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INTRODUCTION.

During the summer of 1913 the Secretary of Agriculture established a board to reorganize the system of publications of the Department of Agriculture. In accordance with the proceedings of the board and the suggestions from representatives of the Weather Bureau, the "Bulletin of the Mount Weather Observatory" ceased to be published with the completion of its volume 6. Any subsequent contributions from the members of the research staff that would have been proper for that Bulletin will be incorporated in the Monthly Weather Review. The climatological service of the Weather Bureau will be maintained in all its essential features, but its publications, so far as they relate to purely local conditions, will be incorporated in the monthly reports for the respective States, Territories, and colonies.

Beginning with January, 1914, the material for the Monthly Weather Review will be prepared and classified in accordance with the following sections:

SECTION 1.—*Aerology.*—Data and discussions relative to the free atmosphere.

SECTION 2.—*General meteorology.*—Special contributions by any competent student bearing on any branch of meteorology and climatology, theoretical or otherwise.

SECTION 3.—*Forecasts and general conditions of the atmosphere.*

SECTION 4.—*Rivers and floods.*

SECTION 5.—*Bibliography.*—Recent additions to the Weather Bureau library; recent papers bearing on meteorology.

SECTION 6.—*Weather of the month.*—Summary of local weather conditions; climatological data from regular Weather Bureau stations; tables of accumulated and excessive precipitation; data furnished by the Canadian Meteorological Service; monthly charts Nos. 1, 2, 3, 4, 5, 6, 7, 8, the same as hitherto.

In general, appropriate officials will prepare the six sections above enumerated; but all students of atmospherics are cordially invited to contribute such additional articles as seem to be of value.

The voluminous tables of data and text relative to local climatological conditions that have during recent years been prepared by the 12 respective "district editors" will be omitted from the Monthly Weather Review, but will in future be collected and published by States at selected section centers.

The data needed in section 6 can only be collected and prepared several weeks after the close of the month whose name appears on the title page; hence the Review as a whole can only issue from the press within about eight weeks from the end of that month.

The Annual Summary of the Review will hereafter appear as an Annual Supplement containing the essential tables heretofore published in the annual Report of the Chief of the Weather Bureau.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are especially due to the following directors and superintendents:

The Meteorological Service of the Dominion of Canada.

The Central Meteorological and Magnetic Observatory of Mexico.

The Director General of Mexican Telegraphs.

The Meteorological Service of Cuba.

The Meteorological Observatory of Belen College, Habana.

The Government Meteorological Office of Jamaica.

The Meteorological Service of the Azores.

The Meteorological Office, London.

The Danish Meteorological Institute.

The Physical Central Observatory, St. Petersburg.

The Philippine Weather Bureau.

The General Superintendent United States Life-Saving Service.

SECTION I.—AEROLOGY.

PRINCIPIA ATMOSPHERICA: A STUDY OF THE CIRCULATION OF THE ATMOSPHERE.[1]

By W. N. SHAW, LL. D., Sc. D., F. R. S., Director of the Meteorological Office, London.

(An address delivered at the request of the council before the Royal Society of Edinburgh, on December 1, 1913.)

[Read December 1, 1913. MS. received December 12, 1913.]

Synopsis.

SECTION I.—AXIOMS OR LAWS OF ATMOSPHERIC MOTION.

1. *The Law of the Relation of Motion to Pressure.*

In the upper layers of the atmosphere, the steady horizontal motion of the air at any level is along the horizontal section of the isobaric surfaces at that level, and the velocity is inversely proportional to the separation of the isobaric lines in the level of the section.

2. *The law of the Computation of Pressure and of the Application of the Gaseous Laws.*

The pressure at any point in the atmosphere and at any instant is the weight of the column of air which stands upon one unit of horizontal area containing the point. The numerical values of pressure, temperature, and density at any point of the atmosphere are therefore related by the usual formulæ for the gaseous laws.

3. *The Law of Convection.*

Convection in the atmosphere is the descent of colder air in contiguity with air relatively warmer.

4. *The Law of the Limit of Convection.*

Convection in the atmosphere is limited to that portion of it, called the troposphere, in which there exists a sensible fall of temperature with height. The upper layer of the atmosphere, in which there is no sensible fall of temperature with height and therefore no convection, is called the stratosphere.

5. *The Law of Saturation.*

The amount of water vapor contained in a given volume of air can not exceed a certain limit, which depends upon the temperature and upon nothing else.

SECTION II.—LEMMAS OR POSTULATES.

Lemma 1.—In the stratosphere, from 11 kilometers upward it is colder in the high pressure than in the low pressure at the same level; and in the troposphere, from 9 kilometers downward to 1 kilometer, it is warmer in the high pressure than in the low pressure at the same level. [W. H. Dines, *M. O.*, 210*b*.]

Lemma 2.—The average horizontal circulation in the Northern Hemisphere in January between 4 kilometers and 8 kilometers consists of a figure-of-eight orbit from west to east along isobars round the pole, with lobes over the continents and bights over the ocean.

The average circulation at the surface is the resultant of the circulation at 4 kilometers combined with a circulation in the opposite direction of similar shape due to the distribution of temperature near the surface. [L. Teisserenc de Bort, *Ann. du Bureau Central Météorologique*, 1887; and W. N. Shaw, *Proc. Roy. Soc.*, vol. lxxiv, p. 20, 1904.]

SECTION III.—PROPOSITIONS.

Proposition 1.—To define the conditions for the persistence of the existing motion of the atmosphere.

Proposition 2.—To show that the rate of increase of pressure difference per kilometer of height is $34\cdot2\frac{p}{\theta}\left(\frac{\Delta\theta}{\theta}-\frac{\Delta p}{p}\right)$; and hence that the distribution of pressure in the stratosphere is the dominant factor in the circulation of the air at the surface; that the intermediate layers between 4 kilometers and 8 kilometers exert little influence upon the distribution of pressure.

Proposition 3.—To show that the wind velocity across the slope of pressure at any level is proportional to $\theta\frac{\Delta p}{p}$; and thence to show how to utilize observations of the pressure and temperature to calculate the wind velocity at any level.

Proposition 4.—To show that the wind velocity generally increases with height until the substratosphere is reached, and falls off with increase in height in the stratosphere.

Proposition 5.—To show how the distribution of pressure and temperature in the upper air can be calculated from the observations of structure represented by a sounding with a pilot balloon, and thence to account for the local distribution of rainfall when an upper current from the northwest crosses a lower current from the southwest.

Proposition 6.—To account for the average general circulation over the Northern Hemisphere in the 4-kilometer level as set out in Lemma 2.

INTRODUCTION.

Every science has two aspects or two stages in its development. In the first, the inductive stage, observations are made and compiled, and axioms or laws are laid down. In the second or deductive stage the laws are applied by syllogistic reasoning, mathematical or otherwise, to elicit conclusions which either disclose new facts or show the inevitable connection between facts already known, and, in either case, complete the claim of the study to the rank of a science.

The different sciences vary greatly in the stage of development which they present. The science of geometry has almost forgotten the origin of its own laws and axioms, and occupies itself with the most complicated deductive propositions, the forms of which are used to guide the deductions of other sciences. Biology is still in the inductive stage; no one ventures yet to predict in what form the horse will be found a million or even a thousand years hence.

These different aspects of science appeal with different force to different types of human mind. Observers are comparatively rare; true inducers, those who have the patience and the insight to arrange the facts and formulate the underlying laws are extremely rare; deducers, those who draw conclusions, not always mathematical or strictly logical, make up the balance of the human race.

Many years ago, in 1862, Dr. Alexander Buchan, in a contribution to this society which was subsequently elaborated in a volume of the results of the *Challenger* Expedition, laid the foundations of our inductive knowledge of the atmospheric circulation by a series of maps of the distribution of pressure over the surface of the globe. With great pleasure I take the opportunity afforded to me by your invitation to address you on recent developments of the science of meteorology particularly

[1] *Reprinted from* Proc. Roy. Soc. Edinb., 1913-1914, **34**, 77-112, as issued separately Mar. 23, 1914.

in the investigation of the upper air, to put before you a representation of the knowledge of the atmospheric circulation as it presents itself to my mind, arranged in the normal scientific form, with axioms which represent inductive laws, with postulates or lemmas which represent groups of observed facts, and with propositions leading to conclusions which are susceptible of verification.

SECTION I.—AXIOMS OR LAWS OF ATMOSPHERIC MOTION.

The time has arrived when it seems possible and desirable to formulate the laws and principles which can be effectively employed at the present day in the explanation of many of the recognized phenomena of the structure and circulation of the atmosphere and to illustrate their application. These laws and principles are the result of observations sometimes suggested or controlled by theory. They are of the nature of axioms or inductions, about the validity of which a good deal of discussion is possible. Into that discussion I do not now propose to enter. The axioms really depend for their justification upon their effectiveness in explaining observed facts. They are set out as follows:

1. *The law of the relation of motion to pressure.*

In the upper layers of the atmosphere, the steady horizontal motion of the air at any level is along the horizontal section of the isobaric surfaces at that level, and the velocity is inversely proportional to the separation of the isobaric lines in the level of the section.

The line of argument in favor of this law, which can not, strictly speaking, be either verified or contradicted by any available process of observation, is as follows: The condition specified in the law is the condition of kinematic equilibrium toward which all atmospheric motions tend, and have tended either since the earth began to rotate as it does now, or the atmosphere was first formed, whichever of those events is the later in time. Any deviation from the equilibrium state is by infinitesimal steps during which readjustment to the equilibrium condition has been taking place automatically. Hence any finite difference from the equilibrium state can only occur in quite exceptional conditions. Consequently if there is an ascertained difference from the equilibrium condition it requires explanation, just as the divergences from the uniformity contemplated by the First Law of Motion require explanation.

An allowance for "curvature of path" is one of the differences of which account may have to be taken. Its importance depends upon the latitude. For the half of the globe north of 30° N. and south of 30° S. it is generally negligible, but near the equator it becomes the paramount consideration in the question of the persistence of distribution. Thus rotary systems, small or large, are the only possible isobars for a synchronous chart of an equatorial region, if one were drawn. The long sweeps of "parallel isobars" with which we are concerned in this paper would be inadmissible there.

Near the surface there is always a component of motion along the gradient from high pressure to low pressure. In this region the friction due to obstacles and to the viscosity of the air prevents the steady state being reached, and in consequence the centrifugal force due to the velocity of motion is not adequate to balance the pressure.

This modification of the general principle in the case of surface air may be inferred from the fact that in all maps of the distribution of pressure and wind at the surface there is evidence of a flow across the isobars. The maps are not always conclusive, as they are for sea level and not station level; but no person of experience will doubt the general truth of the statement, which in books often takes the form of postulating convergence toward centers of low pressure and divergence from centers of high pressure.

2. *The law of the computation of pressure and of the application of the gaseous laws.*

The pressure at any point in the atmosphere and at any instant is the weight of the column of air which stands upon one unit of horizontal area containing the point.

This principle assumes that the motion of the air is so slow that the hydrostatical forces are not interfered with. Explosion or elastic wave motion would invalidate the law. It therefore assumes that the atmosphere is free from explosions and elastic wave motions, or that their effect is so small that it does not enter into meteorological calculation.

It follows that the numerical values of pressure, temperature, and density at any point of the atmosphere are related by the usual formulæ for the gaseous laws. In other words, when due allowance is made for the difference of composition in consequence of the variation in the amount of water vapor or other possible causes, the relation $p = R\theta\rho$ holds, where p, θ, ρ are the pressure, temperature (on the absolute scale), and density of the air, and R is a "constant" which is altered by an alteration in the composition of the air but not by other causes.

3. *The law of convection.*

Convection in the atmosphere is the descent of colder air in contiguity with air relatively warmer.

The law is advisedly stated in this form (although objections may be taken to it for want of strictness) because the driving power of the convective circulation comes from the excess of density of the descending portion, and the excess of density in atmospheric air is due in nearly all cases to low temperature. Differences of density might be caused by differences of pressure or by differences in the amount of moisture contained in equal volumes; but finite differences of pressure cannot persist in contiguous masses of air. The amount of water vapor in air at the ordinary temperatures with which a meteorologist has to deal is only a small fraction of the whole mass, and the colder the air is the less water vapor is required to saturate it. Consequently, although it would be possible in a physical laboratory to display a sample of air which though warmer is yet denser than another cooler sample on account of the humidity of the latter, the conditions would not easily occur in nature, and the motive power for convection would be exceedingly small. Such cases may therefore be left out of account, and we may consider that of two contiguous masses of air the colder is the denser.

The law of convection is usually stated with regard to the warmer part of the convective circulation and takes the briefer form that warm air rises. The general adoption of this briefer form is due to the fact that the warming of air at the surface is a matter of common knowledge and it occurs in the daytime, when its effects in producing a local convective circulation are often quite distinctly visible. The form which is adopted here, however, is preferable, because in any case it is the cooler and heavier air in the neighborhood which must be looked for if the

true cause of the circulation is to be found, and although on the smaller scale the heavier air is not far to seek, it is not so easily identified on the scale of a meteorological chart.

Convection in the atmosphere may also be due to the variation in the gravitational acceleration due to the motion of the air with reference to the earth.

The gravitational acceleration depends partly on the statical attraction of the earth's mass and partly on the centrifugal action due to rotation. The ordinary values of the constant of gravitation assume the rotation to be that of the solid earth, and the acceleration of gravity upon air moving over the earth's surface is consequently different from that for calm air. Hence the air which forms part of a westerly wind is *specifically lighter* than air at the same temperature and pressure which is calm, and, on the other hand, air which forms part of an easterly wind is *specifically heavier*. These variations in what, contrary to the usual convention, may rightly be called the "specific gravity of the air" have not yet been generally taken into account in meteorological practice, but they are of real significance and are the subject of certain classical papers by von Helmholtz and Brillouin on the circulation of the atmosphere.

4. *The law of the limit of convection.*

Convection in the atmosphere is limited to that portion of it in which there exists a sensible fall of temperature with height.

This portion, which comprises about three-fourths of the atmosphere, is called the *troposphere* and is a layer of air about 10 kilometers thick surrounding the whole earth. It is surrounded by an outer spheroid of air comprising the remaining fourth part of the atmosphere, which is called the *stratosphere*, in which there is no sensible fall of temperature with height. The boundary between these two layers is not at a fixed height; it is apparently a flexible, and therefore deformable surface, but it is not penetrable by air.

The height of the boundary differs in different latitudes, being highest over the equator and getting gradually lower towards the poles; it differs also in different localities, being higher over an area of high pressure than over one of low pressure. The local differences are due to deformations of the boundary by the accumulation or withdrawal of air from underneath. At any place the boundary oscillates about a mean position which should be regarded as the height of the boundary of the stratosphere for the place. There is no physical reason why the boundary of the stratosphere should not be penetrated. All that is required to produce that effect is an accumulation of air warm enough to cause upward convection. All that can be said is that there is no example of the approach to such an accumulation. There are a sufficient number of examples in which there is a reversal of fall of temperature just below the stratosphere, and these show that the stratosphere has, if anything, a little to spare in the way of resistance against penetration. Hence, from the point of view of meteorological theory, we regard the stratosphere as impenetrable.

5. *The law of saturation.*

The amount of water vapor contained in a given volume of air cannot exceed a certain limit which depends upon the temperature and upon nothing else.

This is really simply a statement of Dalton's law of the saturation of a gas with the vapor of a liquid, but it is quoted here partly because it refers to the only form of variation in chemical composition to which the meteorological atmosphere is subject, and also partly in order to avoid a misapprehension that is very widespread. It is a well-known physical principle that when a vapor is condensed the "latent heat of vaporization," which, in the case of water vapor, is very large, is liberated. The statement of the principle is not complete; it should go on to say that the condensation cannot take place unless provision has been made for disposing of the heat which will be liberated. In the case of the atmosphere it is often assumed that no provision of the kind is required, and that the air will, in consequence, *be warmed* by the heat set free. Herein lies the misapprehension. Vapor of water in air will not condense unless the air is cooled, and the amount of condensation will be limited by the amount of the cooling.

It should, however, be noted that the wording of the law as here given, namely, that the limiting amount of water vapor depends upon the temperature *and upon nothing else*, implies a statement about the atmosphere about which it is necessary to be explicit. Since Dalton's law was enunciated, the researches of Aitken and others have shown that the cooling of a mass of air below the "saturation point" causes condensation only if there are nuclei upon which drops of water can form. In the absence of such nuclei, laboratory experiments have shown that condensation does not take place until the limits of saturation have been largely exceeded; "four-fold saturation" is necessary in such a case. Air without nuclei cooled below its "saturation point" is said to be supersaturated, and the statement of the law of saturation as set out implies that *supersaturation does not exist in the free air*. This is another case in which there is no physical reason to prevent anyone imagining circumstances in which supersaturation might exist; all that can be said is that no such circumstances have been demonstrated, and the ready formation of clouds at all heights seems to indicate that such circumstances are quite unlikely. Hence the meteorologist is entitled to infer, as the result of a meteorological though not of a physical law, that *condensation* in the form of cloud, or if necessary of rain, *will always accompany the reduction of temperature of the air below the point of saturation*, and the amount of condensation will depend upon the reduction of temperature and upon nothing else.[2]

These five laws express the special principles with which the meteorologist must approach the consideration of the circulation of the atmosphere, with all its complexities and its perplexities. The rest must depend upon the application of the ordinary principles of dynamics and physics to the results of observations which indicate the pressure, temperature, and density of the air in its actual condition when under consideration. It is my object in this paper not to discuss or to justify these principles, but to show how far they lead us in the explanation of some of the more general phenomena of the atmospheric circulation.

The form which has been adopted for this communication has been chosen for the purpose of drawing a distinction between the inductive, the observational, and the deductive aspects of the questions which are treated. Just as, in the cases of motion treated in text-books of dynamics, there is ample opportunity for discussion as to the form of words which shall be used for the laws of motion and the grounds for their acceptance or rejection,

[2] The supersaturation of atmospheric air is discussed in Dr. Alfred Wegener's Thermodynamik der Atmosphäre, Leipzig, J. A. Barth, 1911. Humidities, by the hair hygrometer, up to 107 per cent are cited on p. 254 of that work.

starting from the consideration that there never has been an actual example of a body free from the action of force, so, in the case of atmospheric motion, there is no lack of opportunity for the discussion of the laws as here set out, starting from the consideration that no actual case can be quoted in which we are certain that the laws are strictly obeyed. And further just as in the case of the dynamics of the heavenly bodies the whole subject is reduced to a manageable form by setting out to explain the changes of motion and their causes instead of pondering over the ultimate origin and cause of the state of motion which exists at any particular epoch, so in the study of the circulation of the atmosphere we may profitably turn our attention to the changes in the motion related to the varying distributions of pressure, and leave for the time being the endeavour to give a short answer to the question, "What is the ultimate cause of any given distribution of pressure, with its attendant atmospheric motion?"

We proceed, therefore, first to define in two lemmas the average condition of the atmosphere which we wish the reader to keep in mind, and secondly to apply the laws which have been already enunciated to make certain deductions or establish certain propositions with regard to the circulation of the atmosphere, which are set out in the synopsis.

SECTION II.—LEMMAS OR POSTULATES.

Lemma 1.

In the stratosphere from 11 kilometers upward it is colder in the high pressure than in the low pressure at the same level; and in the troposphere, from 9 kilometers downward to 1 kilometer, it is warmer in the high pressure than in the low pressure at the same level.

Proof.—Table of average values of pressure and temperature at different levels over high pressure (1031 *mb.*) and low pressure (984 *mb.*) at the surface; with pressure differences and temperature differences at each level. Compiled from the diagram and tables of W. H. Dines, F. R. S., in *Geophysical Memoirs*, No. 2, M . . Publication, 210*b*.

TABLE 1.

Altitude.	Pressure.		Diff.	Diff.	Temperature.	
	Low.	High.	$\triangle p$.	$\triangle\theta$.	984 *mb.* low.	1031 *mb.* high.
km.	*mb.*	*mb.*	*mb.*	°*A.*	°*A.*	°*A.*
15	116	123	7	....	...	...
14	135	146	11	− 9	224	215
13	157	171	14	−11	226	215
12	183	201	18	− 8	225	217
11	212	235	23	− 4	225	221
10	247	273	26	+ 1	225	226
9	288	317	29	+ 7	226	233
8	335	366	31	+13	227	240
7	388	422	34	+15	232	247
6	449	483	34	+14	240	254
5	516	552	36	+13	248	261
4	591	628	37	+12	255	267
3	675	713	38	+ 9	263	272
2	767	807	40	+ 8	269	277
1	870	913	43	+ 4	275	279
0	984	1031	47	+ 3	279	282

Standard deviation of P_9 13.8 mb.
Standard deviation of P_s 14.1 mb.
Correlation coefficient between the variations of P_9 and P_s from the means for the month (English ascents) 0.80.

The table which is here given summarizes the results of an important investigation by Mr. Dines into the relation between the changes of pressure at the 9-km. level and the corresponding changes at the surface. The changes which he dealt with were chronological, and I have extended the conclusion in applying it to topographical differences. This extension is justified if the places between which the differences are to be taken are sufficiently close together to be influenced by the same barometric system, and if the chronological sequence is followed in individual cases. That the latter condition is generally satisfied is shown by the high correlation coefficient between the variations at 9 km. and at the surface.

The conclusion as to the relation between temperature and pressure in the upper air, which is drawn from this table, is supported by the gradual evolution of meteorogical ideas on the subject. Originally it was assumed that high pressure meant relatively dense air and low pressure relatively light air from the surface upward. Sometimes temperature and sometimes moisture was held accountable for the levity; but the view first put forward by von Hann that, in ordinary circumstances, the air over high pressure is warmer than that over low pressure has gradually developed until it may now be regarded as an accepted principle in meteorology. It is borne out by the simultaneous soundings which have occasionally been obtained from places within the same barometric system; and apparently the disturbances in the specified order are mostly confined to the lowest reaches of the atmosphere. This last point also is well illustrated by the figures of the table, which show a gradual falling off, on the average, of the temperature differences in the lowest three kilometers.

Lemma 2.

The average horizontal circulation in the Northern Hemisphere in January between 4 kilometers and 8 kilometers consists of a figure-of-eight orbit from west to east along isobars round the pole, with lobes over the continents and bights over the oceans.

The average circulation at the surface is the resultant of the circulation at 4 kilometers combined with a circulation in the opposite direction of similar shape due to the distribution of temperature near the surface.

[L. Teisserenc de Bort, *Ann. du Bureau Central Météorologique*, 1887; and W. N. Shaw, *Proc. Roy. Soc.*, vol. lxxiv. p. 20, 1904.]

This lemma is introduced in order to supply the reader with a suitable general picture of the atmospheric circulation in the upper air, and the modification which it must undergo in the lowest layers in consequence of the distribution of temperature near the surface. As will be seen from Proposition 2, which follows, the similarity of pressure-distribution at all heights depends upon the equality of $\triangle\theta/\theta$ and $\triangle p/p$. Consequently, a circulation along parallels of latitude from west to east in which the air nearer the poles is the colder is a circulation which may remain practically identical at all heights, and is suggestive of durability and persistence.

The distribution of pressure at the 4-km. level given by M. Teisserenc de Bort suggests that the actual circulation in the upper air is not a circulation along parallels of latitude, but yet is an approximation thereto, being something intermediate between a circle and a figure-of-eight.

That the circulation at the 4-km. level remains of the same general character up to the 8-km. level is suggested by the fact that in those regions distribution of temperature is such as to cause very little change in pressure differences, in accordance with the formula of Proposition 2.

It may be remarked that the distribution was calculated by M. L. Teisserenc de Bort from the distribution

of pressure and temperature at the surface, and is subject to two uncertainties, first, the reduction of the original pressure readings to sea level; and, secondly, their further reduction to the 4-km. level. The uncertainties arise from the uncertainty in the values of the temperature of the air "below the ground" in the reduction to sea level and above the ground in the reduction to the 4-km. level. To a certain extent these two uncertainties compensate each other in the important features of the result, and the conclusion as to the circulation at which M. Teisserenc de Bort had arrived is supported by the results of Hildebrandsson's discussion of the international cloud observations (see Hildebrandsson and Teisserenc de Bort, *Les Bases de la météorologie dynamique*, vol. ii, Gauthier-Villars, Paris), and by other considerations of a more general character.

The statements of these two lemmas are based upon observation and are therefore liable to modification or correction in detail as the results of observation become more conclusive. They are, however, sufficiently well established to justify their use in the further consideration of meteorological problems.

SECTION III.—PROPOSITIONS.

We now proceed to the consideration of the propositions which are set out in the synopsis. I shall deal in detail with only three of the propositions, numbered 1, 5, and 6, respectively, because the remaining three, numbered 2, 3, and 4, have already been dealt with in a paper communicated to the Scottish Meteorological Society, with the title of "The Calculus of the Upper Air, and the Results of the British Soundings in the International Week of May 5–11, 1913." The paper is published in the *Journal* of the society for 1913.

Proposition 1.—The conditions necessary to maintain a steady atmospheric current.

The conditions which must be complied with if a steady current is to be persistently maintained must satisfy the first law, the law of relation of motion to pressure.

The law prescribes that the velocity V is related to the pressure gradient γ, density ρ, latitude λ, and the angular velocity of the earth's rotation ω, by the equation

$$V=\gamma/(2\omega\rho\sin\lambda).$$

Provided that the latitude λ remains constant during the persistence of the current this condition presents no difficulty; the flow will always be determined by the distance apart of the isobars, but the auxiliary condition that the current shall not change its latitude implies that the isobars are parallel to the circles of latitude. Hence we may infer that, neglecting a very small correction for curvature, a circulation round the pole along isobars parallel to the circles of latitude is a "steady" circulation which will be persistently maintained. The only forces which will interfere with it are frictional forces due to the relative motion of adjacent layers of air, and, except in the immediate neighborhood of the ground where friction is aided by turbulent motion, these are extremely small. Hence a west-to-east circulation or an east-to-west circulation in the upper air once steady will remain so, unless it is disturbed by changes of pressure distribution.

But, on the contrary, when the air movement is from south to north or from north to south, or has any component which gives a motion across the circles of latitude, a change in $\sin\lambda$ has to be dealt with.

Motion from south to north.

We propose to deal first with a current moving from south to north. We shall suppose the current to be uniform over the section *from the one-kilometer level upwards.* We leave out the lowest kilometer because we know that it is disturbed by quasi-frictional forces at the surface.

In this case the value of $\sin\lambda$ is increasing, and therefore greater pressure difference is required to get the same quantity of air through the same section. But the pressure difference is limited by the isobars, which are by hypothesis supposed steady. Any convergence of the isobars themselves provides its own remedy, because the gradient velocity is inversely proportional to the distance. We have therefore only to deal with the change in $\sin\lambda$ in the formula

$$V=\gamma/(2\omega\rho\sin\lambda).$$

Let L be the width of the current, and H its depth; then the flow over the whole section $L\times H$ is LHV; and by the equation of continuity this must be constant as the stream flows northward.

Now

$$LHV=\frac{HL\gamma}{2\omega\rho\sin\lambda},$$

and $L\gamma$ is the pressure-difference, Δp, between the two sides of the current. LHV is constant; hence, differentiating, we get

$$0=\frac{\partial H}{H}-\frac{\partial\rho}{\rho}-\frac{\partial\sin\lambda}{\sin\lambda}$$

or

$$\frac{\partial H}{H}=\frac{\partial\rho}{\rho}+\cot\lambda\,\partial\lambda.$$

Now ρ can only alter by variation of pressure, temperature, or composition; change of pressure is ruled out because the motion is along isobars; change of temperature will be very slight because there is no change of pressure, and there are no other causes of any appreciable change of temperature; and change of composition can only occur in consequence of condensation. By Law 5, in the absence of change of temperature no change of composition will occur. Hence

$$\partial\rho/\rho=0,$$

and

$$\frac{\partial H}{H}=\cot\lambda\delta\lambda.$$

In other words, the thickness of the moving layer must increase fractionally by the amount $\cot\lambda\delta\lambda$ *for the change of latitude* $\delta\lambda$. If latitude is expressed in degrees and not in circular measure as differentiation supposes, we must introduce the factor $\frac{\pi}{180}$, and thus the formula becomes

$$\frac{1}{H}\cdot\frac{dH}{d\lambda}=0\cdot0175\cot\lambda.$$

Hence, in order that a current may persist over any stretch from south to north, *it is necessary that the thickness of the moving layer should increase fractionally to the extent of* $0\cdot0175\cot\lambda$ *for every degree of latitude which it crosses.*

We have assumed the layer to be unlimited above, and limited below by the one-kilometer level. To provide for the additional air by increasing the height above the selected base-level would result in altering the pressure: that mode of operation is therefore excluded by

the condition of maintenance of the current as steady. Consequently we must suppose the additional thickness to be provided by encroachment upon the lowest kilometer: that region is already supposed to be occupied by an extension of the current which is disturbed by surface friction; hence, *unless there is a continual flow-off of air from below the one-kilometer level, the steady state can not be maintained.*

The south-to-north current implies a high pressure on the eastern side and a low pressure on the western side, and near the surface there is a component of flow from high to low across the isobars. Hence we may suppose a case in which the northward-flowing current is maintained steady by the flow-off from east to west in the surface layer. We proceed to calculate the amount of this east-to-west current which will suffice to draw off the increase of the current above 1 kilometer.

We suppose, for the purpose of calculation, that the east-to-west component is uniform over the lowest half kilometer of the western section. The fractional increase of thickness in the upper layer has been shown to be $0 \cdot 0175 \cot\lambda$ for each degree of advance northward. The increase of the thickness is the same over each elementary layer of height into which the whole thickness can be divided; consequently the air to be removed is the fraction $0 \cdot 0175 \cot \lambda$ of the transverse vertical section at every level. If the removal is confined to the lowest half kilometer, which contains a fraction of the atmosphere approximately one-twentieth of the whole, it follows that a fraction $20 \times 0 \cdot 0175 \cot \lambda$ of the lowest half-kilometer layer has to be removed for each degree of advance northward.

For each *meter* of advance northward, therefore, a fraction $\frac{20 \times 0 \cdot 0175 \cot \lambda}{111 \cdot 1 \times 10^3}$ of the lowest half-kilometer layer has to be removed; and, similarly, for each *meter per second* of the wind velocity from south to north a fraction $\frac{20 \times 0 \cdot 0175 \cot \lambda}{111 \cdot 1 \times 10^3}$ must be removed *every second.*

Suppose that the breadth of the advancing current which is supposed to be maintained steady is L kilometers, the westerly flow at the western end of the lowest half kilometer must carry away air at the rate of $\frac{20 \times 0 \cdot 0175 \cot \lambda}{111 \cdot 1 \times 10^3} \times L$ kilometers per second, or there must be a cross component of wind there amounting to $\frac{20 \times 0 \cdot 0175 \cot \lambda}{111 \cdot 1} \times L$ meters per second.

If the cross wind be referred to the width of a current expressed in degrees of longitude at the latitude λ, and if l be the width of the current in degrees, we get

$$L = 111 \cdot 1 \cos \lambda l.$$

Whence it follows that in order to maintain a south-to-north current of V meters per second there must be a cross wind leaving the lowest half kilometer of

$$0 \cdot 35 \cos^2\lambda \frac{lV \text{ meters per second}}{\sin \lambda}.$$

We have supposed the drainage to take place entirely in the lowest half kilometer, which represents one-twentieth of the atmosphere. The same result might be produced by a distributed crossflow throughout the western vertical section of the moving air of $0 \cdot 0175 \frac{\cos^2\lambda}{\sin\lambda} lV$ meters per second.

We may therefore sum up the conclusion as follows: *In order that a current across circles of latitude from south to north with a breadth of l degrees of longitude may persist unaltered at any level, it is necessary that air should be drawn away from the moving air at that level to the extent of* $0 \cdot 0175 \frac{\cos^2\lambda}{\sin\lambda} lV$ *meters per second.*

The use of the surface layer, to draw off the excess of air which would otherwise prevent the persistence of a current across circles of latitude, is quite appropriate in the case of currents with a south-to-north component. According to the rider to Law 1, such a current certainly exists, and it only requires its magnitude to be adjusted in order that persistence may be secured. For a current extending over 10° of longitude in latitude 45° the cross component at the extreme west of the lowest half kilometer would have to be two and a half times the steady south wind above, and that hardly occurs in practice; but there are a variety of ways of accounting for any dis-

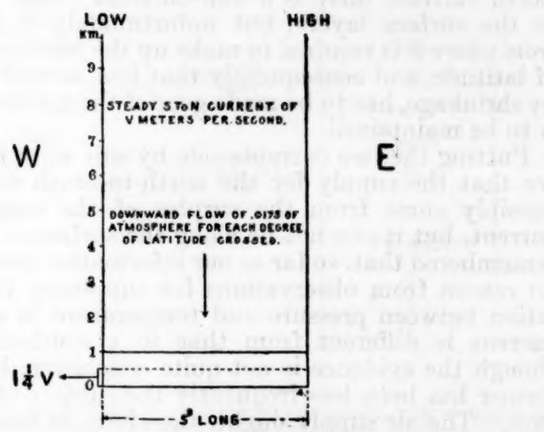

FIG. 1.—Cross section of 9 kilometers [1 km. to 10 km.] of a south to north current 5° wide, "maintained" in latitude 45°.

crepancy between the calculated and observed cross wind in case the south-to-north current is actually maintained. Hence the diagram, figure 1, representing the conditions for maintenance of a south wind across a section of 5° of longitude is not unreasonable.

The representation is, moreover, borne out by the facts which are known as to the distribution of temperature in the atmosphere. For the 7 kilometers between the 1-km. level and the 8-km. level the temperature on the "high" side is "too warm," and therefore represents the effect of a downward flow while the pressure is maintained.[3] Hence it seems possible for the conditions for the maintenance of a south-to-north current to be realized in practice, though the adjustment would be delicate and might certainly be transient.

Motion from north to south.

Persistence in the reverse of the case just described, that is to say, in the case of a current flowing from north to south, is in one respect more difficult and in another more easy.

What we have to provide for here is not the thickening but the shrinkage of the current in consequence of the

[3] See the paper in the *Journal of the Scottish Meteorological Society* already referred to.

decrease of $\sin\lambda$ as successive circles are crossed. The numerical result applies equally, but in the opposite sense. Thus a current of velocity V flowing from north to south requires that air should be *fed* with an inflow which, if distributed over the whole side, would be $0{\cdot}0175 \frac{\cos^2\lambda}{\sin\lambda} lV$ at any level at which the wind velocity is V, in order to avoid fractional shrinkage of $0{\cdot}0175 \cot\lambda$ per degree of advance. It is more difficult to see how the air could be supplied; but the shrinkage of the current, while the distribution of pressure which controls it is maintained, presents little difficulty if the current in question may be supposed to remain an upper air current and therefore subject only to the pressure-distribution appropriate to the current. To explain the persistence of a current in the lower layers would make greater demands upon one's ingenuity, because the introduction of the necessary air would, as a rule, alter the distribution of pressure below, and limitations to prevent that alteration would have to be invented. Hence the maintenance of a current from north to south at all levels requires some artifice for the continuous production of the necessary pressure-distribution. The difficulty is further aggravated by the fact that, just as in the case of the south-to-north current, there is a flow-off from "high" to "low" in the surface layers; but unfortunately it flows *away from where it is required* to make up the loss due to change of latitude, and consequently that loss, as well as the loss by shrinkage, has to be made good if the northerly current is to be maintained.

Putting the two currents side by side as in figure 2, we see that the supply for the north-to-south current may possibly come from the surplus of the south-to-north current, but it can not be along the surface. It must be remembered that, so far as our information goes, we have no reason from observations for supposing that the relation between pressure and temperature in a northerly current is different from that in a southerly current, though the evidence is not quite conclusive, because the former has been less frequently the subject of investigation. The air supply ought, therefore, to be carried out in a similar manner in both cases. Persistence in this case, therefore, requires the surplus of the adjacent southerly current *and the outflow from the northerly itself* both to be delivered to the northerly current in the upper layers in order that the proper temperature distribution may be obtained.

Such a combination of circumstances may fairly be regarded as exceptional, and therefore the maintenance of a northerly current must be regarded as exceptional.

Changes from the steady state.

To complete the process of maintenance of the steady current from the north we should have to imagine the whole of the outflow in figure 2 toward the "low" from both sides conveyed to the upper part of the northerly current, and thus transferred from low pressure to high pressure as well as from low level to high level. It is possible to make out a process with the aid of the law of convection if the two currents are at different temperatures. In such a case the surfaces of equal pressure may be so sloped as to produce an apparent flow across isobars from low to high; but we have no such obvious and automatic explanation to give in the case of the northly current as in the case of the outflow of the southerly current. And, indeed, it was not intended to adduce the conditions for persistent maintenance with the object of claiming that they are generally satisfied in practice. On the contrary, the adjustment of the outflow in the southerly current to the conditions of persistence must be fortuitous and unlikely to be maintained for long; the adjustment of conditions for the maintenance of a northerly current is even more fortuitous. The reason for setting out the conditions of maintenance is rather to show that natural conditions of atmospheric currents are not, as a rule, those of persistence but of change. If the conditions of persistence which have been set out are not realised, the currents will change, and by Law 1 changes in currents imply changes in the distribution of pressure. Consequently, an atmospheric system which includes northerly or southerly currents has within itself elements and causes of change in the distribution of pressure. It is therefore unnecessary to attribute all changes to outside causes. It is preferable to consider the causes of the changes which are inherent in cases in which we cannot suppose the conditions of maintenance satisfied, and to regard external causes of change which are known to exist as supplementary.

It follows that we have not to regard a quiescent atmosphere all over the globe as the starting-point of our explanation of the present condition, but we have rather to regard the circumstances of transition from one set of conditions to another.

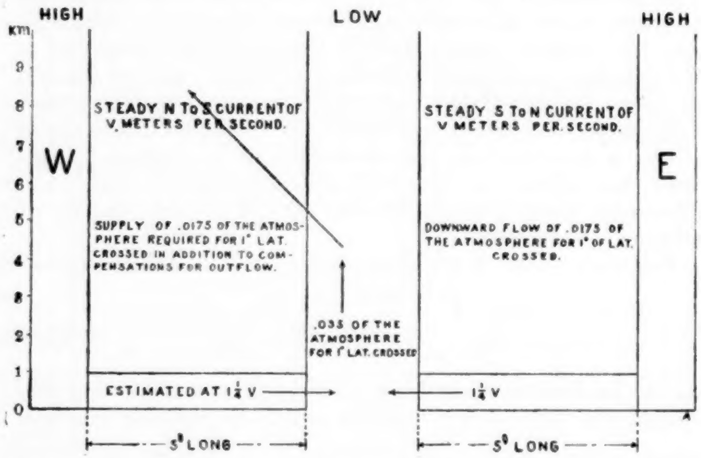

FIG. 2.—Cross section of 9 kilometers [1 km. to 10 km.] of two currents, south to north, and north to south, each 5° wide, "maintained" in latitude 45°.

We may add some notes upon practical cases.

Persistent southerly current.

The maintenance of a southerly current has been shown to be a question of adjustment of velocities, and a southerly current lends itself comparatively easily to persistence. Examples of a persistent southerly current across the parallels of northern Europe furnish a well-recognized type of weather that seems to resist the incursions of cyclones from the west. A southerly current often extends throughout the vertical section of the atmosphere, as might be expected from the automatic thickening described above.

Persistent northerly current.

On the other hand, a northerly current requires constant reinforcement, and yet a northerly current, persistent for days over the northeastern Atlantic, is by no means unknown. It is possible that the necessary air in this case may be supplied by the gravitational flow of cold air off Greenland or northern Siberia, which must contribute a large amount of air to the surface layers above the northeastern Atlantic.

Replacement of a northeasterly current by a southwesterly current.

An example of the disturbance of persistence frequently occurs in the case of a northeasterly current with a southwesterly current above it, a case which is referred to in Mr. Cave's book on the *Structure of the Atmosphere in Clear Weather* as a frequent precursor of weather of the thunderstorm type, accompanied by the setting in of the southwesterly wind. The distribution of temperature is such as to change the direction of the pressure-gradient near the surface. Consequently the outflow from high to low goes from under the upper "low" to under the upper "high." The necessity for the thickening of the southerly current is therefore not relieved by the outflow, but accentuated thereby. At the same time the northeasterly current has to get thinner, so it is gradually replaced by the southwesterly current settling down to the surface. The appropriate redistribution of pressure at the surface accompanies the redistribution of air currents in the vertical section.

These examples are adduced because it seems not improbable that they give us the opportunity of watching the operation of the causes of change which are inherent in any actual state of atmospheric motion.

Let me summarize the attitude which seems to me to be appropriate for the meteorologist to take up in face of the complexities of the atmospheric circulation, by again referring to the position of the astronomer before the final enunciation of the laws of motion. Imagine the perplexity of the astronomer who, finding the heavenly bodies moving in all sorts of directions with all sorts of velocities, set himself to explain the motion which each possessed. To him the laws of motion bring the assurance that it is not necessary for him to explain why a body moves; it is the changes of motion which should occupy his attention. So the meteorologist, looking at the circulation of the atmosphere in obedience to the distribution of pressure, has not to ask himself why the pressure is high here or low there, but rather, "Is the distribution persistent, and if not, are the causes of change inherent in the existing circulation sufficient to account for the changes?" If it be said that, after all, the problem remains the same and the point of view is immaterial, it is right to remember that in astronomy the change in the point of view has simply reduced chaos to law.

From what has been already said, it appears that a steady state of persistent motion of the earth's atmosphere is in the highest degree improbable, because it can only occur in a combination of circumstances which are independently fortuitous; but it is desirable to call attention to a possible case of motion which is quasi-persistent in consequence of two concurrent and persistent infractions of the conditions of steadiness.

If we suppose the south-to-north and north-to-south currents of figure 2 placed back to back so as to form an anticyclonic section instead of the cyclonic section represented in figure 2, we find in juxtaposition a south-to-north current which must get rid of air, and a north-to-south current which must have air in order to maintain itself, and all that is required in order to maintain both currents is a transverse flow of $0{\cdot}0175\frac{\cos^2\lambda}{\sin\lambda}\,lV$ at any level where the current velocity is V from the south-to-north current to the north-to-south current. We can not accept this transverse motion as a part of steady motion, because the motion would not be strictly speaking along the isobars as prescribed by Law 1. But if we could persistently take the momentum necessary for the perturbation of the steady motion in compliance with Law 1 out of the general west-to-east circulation, we could have both the southerly and northerly currents maintained. It is not unreasonable to suppose that, as a westerly circulation has to be diverted northward to produce the northward circulation, the westerly momentum at the various levels may produce the effect described. In this case we should have the permanence of the anticyclonic distribution maintained by the persistent infraction of the law of relation of pressure to wind. At the same time a flow-off at the bottom outward in both cases has to be supplied, and in consequence there is a downward flow under permanent conditions of pressure over both sides of the ridge of "high" which would give the necessary warming of the air of a high-pressure region. Hence the case represented in figure 3 seems to furnish a possible example of a high-pressure region maintained in a quasi-steady condition by a transfer of air across the isobars in consequence of the uncompensated momentum; the flow-off on either

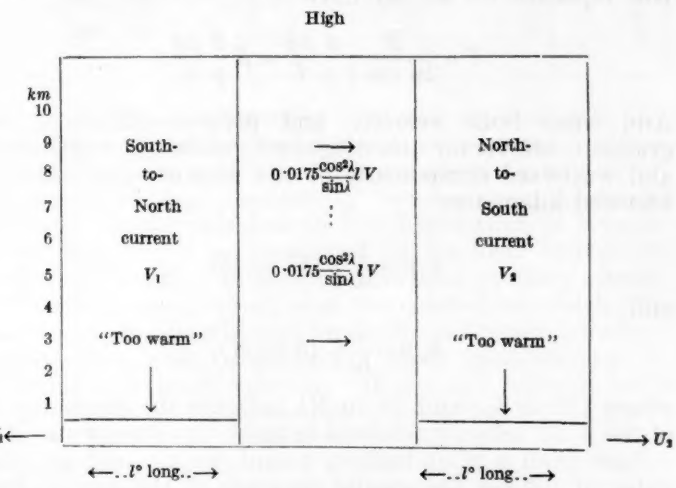

FIG. 3.—South-to-north current, V_1, supplying its own bottom outflow, U_1, and maintaining a parallel north-to-south current, V_2, and its bottom outflow, U_2, by transference of air across the "high" ridge.

side at the bottom from "high" to "low" denoted by U_1 and U_2 being provided by the adjustment of the currents V_1 and V_2.

Whether or not this be a true explanation, it certainly agrees with common experience in regarding a high-pressure area as more easily maintained persistently than a "low."

Propositions 2, 3, and 4.

These propositions, which deal with the application of the formula for change of pressure-difference with height (the unit of height being the meter), viz,

$$\frac{d\Delta p}{dh} = 0.0342\frac{p}{\theta}\left(\frac{\Delta\theta}{\theta} - \frac{\Delta p}{p}\right),$$

to explain the dominance of the stratosphere and the lack of importance of the troposphere in the distribution of pressure at the surface, to compute the wind-velocity from the pressure-difference at any height and to explain the observed falling off of wind-velocity with height in the stratosphere, have been dealt with in the paper communicated to the Scottish Meteorological Society, and the work need not be repeated here, especially as Proposition 5 makes use of the same equations.

Proposition 5.—The calculation of the distribution of pressure and temperature in the upper air from the observations of structure represented by soundings with a pilot balloon.

A pilot balloon gives primarily the horizontal direction and velocity of the wind at successive heights, so that we may suppose that we have the horizontal direction and velocity of the wind at each kilometer as the data for the calculation.

The first step is to resolve the wind-velocity into two components, west to east and south to north.

By the application of Law 1 we can then compute the pressure-difference for 100 kilometers in the south-to-north direction and the west-to-east direction.

Thus, if Δp is the pressure-difference for a distance L taken along the direction of the wind velocity V, if θ, in absolute degrees, and p, in millibars, are the temperature and pressure, λ the latitude, ω the angular velocity of the earth's rotation, and R the constant of the characteristic equation for air, we have

$$V=\frac{R}{2\omega\sin\lambda}\frac{\theta}{p}\frac{\Delta p}{L}=K\frac{\theta}{p}\frac{\Delta p}{L}.$$

And since both velocity and pressure-difference, or gradient, are vector quantities, we get for the northward and westward components of the pressure-gradient per hundred kilometers

$$\Delta_N p=\frac{1}{K}\frac{p}{\theta}\text{ (W to E)}$$

and

$$\Delta_W p=\frac{1}{K}\frac{p}{\theta}\text{ (S to N)},$$

where (W to E) and (S to N) indicate the components of the wind-velocity resolved in those two directions.

Now from a pilot balloon ascent we can not get the value of p/θ for the special occasion of the ascent, but there is really little variation from time to time of this ratio. For the greater part of the troposphere variations of pressure and temperature go together, and the whole range of variation of θ for any particular time of year is less than 10 per cent, and the whole range of variation of p is of the same order. Consequently a mean value of p/θ may be taken as a first approximation for the purposes of the calculation.

The following is a table of average values of p/θ:

TABLE 2.—*Table for values of p/θ at different levels—average of results in "Geophysical Journal," 1912.*

Height.	p/θ.	Height.	p/θ.	Height.	p/θ.	Height.	p/θ.
Km.		*Km.*		*Km.*		*Km.*	
20	0·26	15	0·53	10	1·18	5	2·11
19	·28	14	·64	9	1·35	4	2·35
18	·32	13	·75	8	1·52	3	2·61
17	·39	12	·87	7	1·70	2	2·91
16	·46	11	1·02	6	1·90	1	3·24
						Gd.	3·55

Having thus computed the pressure-difference for 100 kilometers, in two directions at right angles, for the level of each kilometer, we may next obtain by subtraction the change of pressure-difference for each kilometer. The use of the mean value for p/θ will not altogether invalidate the process, because the variation from kilometer to kilometer depends generally on the ordinary diminution of pressure with height rather than on any extraordinary distribution of temperature.

Substituting the value of the rate of increase of pressure-difference per kilometer of height in the equation

$$\frac{d\Delta p}{dh}=34.2\frac{p}{\theta}\left(\frac{\Delta\theta}{\theta}-\frac{\Delta p}{p}\right)$$

and again assuming a value of θ/p, we can compute $\triangle\theta$ provided we have a value of θ which can properly be substituted in the equation.

Here, again, we must have recourse to the mean value, as we have no observation of actual temperature at the time; but, again, the error made is not fatal to the practical success of the calculation, because θ comes in as a factor which affects the scale of the variation; it does not affect the sign. By taking the mean value for the month instead of the actual value the error is probably less than 10 per cent and the whole error of employing mean values for actual values probably amounts to less than 20 per cent; and in considering the distribution of pressure and temperature in the upper air we are not yet in a position to reject observations and information which may be in error by as much as a fifth.

Consequently we may properly use the calculation here indicated to give at least a rough but working idea of the distribution of pressure and temperature at successive levels in the atmosphere when we know the velocity and direction of the wind there.

The errors in p/θ and θ are less important in considering the nature of the distribution, because the same values, right or wrong, are used for both components at the same level.

The following table of monthly averages gives values which may be used in the absence of any special information for the particular occasion:

TABLE 3.—*Average temperature (°A.) at different levels for months.*

1. FOR BRITISH ISLES. TAKEN FROM "GEOPHYSICAL MEMOIRS," NO. 2 (W. H. DINES).

Height.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Km.	°	°	°	°	°	°	°	°	°	°	°	°
14	216	217	219	221	222	223	222	221	219	217	216	215
13	216	217	219	221	222	223	223	221	219	218	217	216
12	217	218	219	220	221	222	222	221	221	219	218	217
11	217	217	217	219	220	221	222	222	221	220	219	218
10	220	220	220	222	224	225	226	226	226	224	223	221
9	224	223	224	226	229	231	234	233	233	231	228	225
8	230	229	230	232	236	238	241	241	241	238	235	332*
7	237	236	237	239	242	245	247	248	247	245	241	238
6	243	243	244	246	249	252	255	255	254	251	249	245
5	250	249	250	252	256	259	261	262	261	258	255	252
4	257	256	257	259	262	265	267	268	267	264	261	258
3	263	262	263	265	268	271	273	274	273	270	267	264
2	267	266	267	270	273	276	278	279	278	275	272	269
1	271	271	273	276	279	282	283	283	281	279	275	272
Gd.	276	276	277	282	285	288	289	289	286	283	280	277

*232° A?—C. A.

I give in Table 3 a specimen of the calculation as applied to the results of a sounding with a pilot balloon on April 29, 1908.

TABLE 4.—*Computation of pressure distribution and temperature distribution from a pilot balloon ascent of April 29, 1908.*

Height.	Velocity.	Direction.	W to E Comp.	$\frac{W \text{ to } E}{K}$ $K=25.4$.	$\frac{p}{\theta}$.	$\frac{W \text{ to } E}{K}\times\frac{p}{\theta}=\triangle_N p$.	Change per km. (increase).	$\frac{\text{Incr. per km.}}{34.2}$	θ.	$\frac{\text{Incr. per km.}}{34.2}\times\theta$.	$\frac{\text{Incr. per km.}}{34.2}\times\theta+\triangle_N p$.	$\left(\frac{\text{Incr. per km.}}{34.2}\times\theta+\triangle_N p\right)\div p/\theta$.	$\frac{1}{\triangle_N \theta}\times 100$.
km.	*m/s.*	°*Az.*	*m/s.*			*mb.*	*mb.*		°*A.*				*km.*
6	20.5	300	+17.75	+0.70	1.88	+1.32	+0.26	+0.0073	248	+1.81	+3.13	+1.66	+ 60
5	15.0	300	+12.99	+ .51	2.08	+1.06	+ .29	+ .0085	254	+2.16	+3.22	+1.55	+ 64
4	8.5	280	+ 8.37	+ .33	2.33	+0.77	+ .12	+ .0035	261	+0.91	+1.68	+0.74	+135
3	6.5	265	+ 6.48	+ .25	2.58	+ .65	− .22	− .0064	267	−1.71	−1.06	− .41	−244
2	8.0	250	+ 7.52	+ .30	2.90	+ .87	+ .33	+ .0091	272	+2.48	+3.35	+1.08	+ 93
1	5.0	240	+ 4.33	+ .17	3.18	+ .54	+ .08	+ .0023	278	+ .64	+1.18	+ .37	+270
0	5.0	220	+ 3.21	+ .13	3.50	+ .46	......	......	......	......	......	......	......

Height.	Velocity.	Direction.	S to N Comp.	$\frac{S \text{ to } N}{K}$ $K=25.4$.	$\frac{p}{\theta}$.	$\frac{S \text{ to } N}{K}\times\frac{p}{\theta}=\triangle_W p$.	Change per km. (increase).	$\frac{\text{Incr. per km.}}{34.2}$	θ.	$\frac{\text{Incr. per k.}}{34.2}\times\theta$.	$\frac{\text{Incr. per km.}}{34.2}\times\theta+\triangle_W p$.	$\left(\frac{\text{Incr. per km.}}{34.2}\times\theta+\triangle_W p\right)\div p/\theta$.	$\frac{1}{\triangle_W \theta}\times 100$.
km.	*m/s.*	°*Az.*	*m/s.*			*mb.*	*mb.*		°*A.*				*km.*
6	20.5	300	−10.25	−0.41	1.88	−0.77	−0.15	−0.0044	248	−1.09	−1.86	−0.98	−102
5	15.0	300	− 7.50	− .30	2.08	− .62	− .48	− .0140	254	−3.56	−4.18	−2.01	− 50
4	8.5	280	− 1.47	− .06	2.33	− .14	− .19	− .0056	261	−1.47	−1.61	− .69	−132
3	6.5	265	+ 0.57	+ .02	2.58	+ .05	− .27	− .0079	267	−2.11	−2.06	− .80	−125
2	8.0	250	+ 2.74	+ .11	2.90	+ .32	0	0	272	0	+ .32	+ .11	+909
1	5.0	240	+ 2.50	+ .10	3.18	+ .32	− .21	− .0061	278	−1.70	−1.38	− .45	−222
0	5.0	220	+ 3.84	+ .15	3.50	+ .53	......	......	......	......	......	......	......

I have used this method for the calculation of the distribution of pressure and temperature in the cases represented by photographs of models in Mr. C. J. P. Cave's book on the *Structure of the Atmosphere in Clear Weather*,[4] which includes that given in detail above. Some of the results are given below—the problem being understood to be stated thus: *Given the wind velocity at any point, to find coordinates for drawing the isobar for the next higher millibar and the isotherm for the next higher degree of temperature.* It will be remembered that the isobar over the point of observation itself is to be taken parallel to the wind direction in accordance with Law 1, and the direction of the isothermal lines will be taken parallel to the line joining the computed coordinates, so that the distribution of pressure and temperature is to be represented each by two parallel lines, the coordinates giving their direction and their distance apart.

1. SOUNDING OF MAY 5, 1909, 6^{h} 43^{m} P. M.

"*Solid current*": *Wind approximately uniform in direction and velocity from 2 kilometers to 10 kilometers.*

TABLE 5.

Height.	Distance of next higher isobar.		Distance of next higher isotherm.	
km.	*km.*	*km.*	*km.*	*km.*
9–10	143 N	233 E	93 N	93 W
8–9	143 N	181 E	1000 N	1250 E
7–8	123 N	291 E	454 S	54 E
6–7	114 N	292 E	137 N	74 W
5–6	99 N	141 E	100 S	139 W
4–5	77 N	110 E	832 N	58 E
3–4	67 N	187 E	303 S	909 W
2–3	58 N	144 E	769 N	196 W
1–2	54 N	353 E	270 N	49 E
0–1	...	...	...	...

In this case it is interesting first to notice the gradual separation of the isobars with increasing height and consequently diminishing density. This is the ordinary condition for the velocity remaining invariable with height.

[4] Cambridge University Press, 1912.

Secondly, it is noteworthy that the separation of the isotherms is generally large and also very irregular, showing approximate equality of temperature in any layer, but great want of conformity between one layer and another. Such variations in the distribution of temperature may easily be accounted for by local convection producing changes of temperature and possibly clouds, and it leads us to reflect that the convection which produces local clouds will also produce local modifications of temperature and consequently local modifications of pressure and wind velocity. If we ask whether such local variations of temperature and wind are at all probable, we have only to refer to the records of the ascents of registering balloons and of anemometers, or of pilot balloon ascents, to give an affirmative answer.

Nothing is more noteworthy than the irregular variations in temperature difference as given by a pair of soundings with registering balloons, and the curious local irregularities of wind disclosed by pilot balloon ascents. Hitherto it has been customary, on quite general grounds, to regard them both as possibly due to the uncertainties of observation. We now see that they may equally well be important evidence of complication in the structure of the atmosphere.

Those whose temperament inclines them that way have still the possibility of uncertainties in observation to fall back upon; but the better plan would seem to be to arrange for simultaneous ascents of registering balloons and pilot balloons, so that the actual and computed distribution of temperature may be compared. The interesting feature of the comparison would be that, if the method of computation here indicated (with its acknowledged uncertainties in taking mean values for p/θ and θ instead of actual values) should prove serviceable, then one pilot balloon ascent gives for practical purposes almost as much information as three registering balloons.

Apart from the uncertainties which have been mentioned, the conclusions as to the distribution of temperature and pressure are incontrovertible by those who accept Law 1, and *per contra* if the conclusions are sustained Law 1 receives its most complete vindication.

2. SOUNDING OF SEPTEMBER 1, 1907.

Westerly wind rapidly increasing aloft.

TABLE 6.

Height.	Distance of next higher isobar.		Distance of next higher isotherm.	
km.	*km.*	*km.*	*km.*	*km.*
4	68 S	∞ E or W	86 S	119 E
3	77 S	400 W	44 S	555 E
2	139 S	294 W	119 S	185 W
1	196 S	526 W	43 S	80 E

The increase in the intensity of the pressure distribution with height is clearly shown and finds its explanation in a steep temperature gradient from south to north.

3. SOUNDING OF NOVEMBER 6, 1908, 10^h 55^m A. M.

Reversal of direction from E.S.E. in the lowest three kilometers to W.N.W. in the reach from 4 kilometers to 9 kilometers.

TABLE 7.

Height.	Distance of next higher isobar.		Distance of next higher isotherm.	
km.	*km.*	*km.*	*km.*	*km.*
8-9	185 S	356 W	96 S	312 W
7-8	204 S	356 W	416 S	770 W
6-7	200 S	416 W	294 S	189 W
5-6	233 S	435 W	139 S	625 E
4-5	344 S	665 W	101 S	109 W
3-4	5,000 S	4,000 E	119 S	270 W
2-3	588 N	416 E	286 S	108 W
1-2	100 N	142 E	24 S	65 W
0-1	77 N	172 E	34 N	40 E

The gradual diminution of velocity up to 4 kilometers where the isobars become very wide apart, is well marked in the second and third columns; and it is seen that the reversal is to be accounted for by a rapid rise of temperature to the southwest in the second and third kilometers, with a similar distribution of temperature of less marked character in the higher layers.

It will be noticed that in the second and third kilometers, where the reversal is determined, the slope of temperature is opposite to the slope of pressure, a condition which we have already noticed as being characteristic of large change of pressure-difference with height. In the sixth kilometer the next higher isotherm is found a long way off on the east instead of on the west, as in the layers above and below. The change is not really very large, as the temperature conditions are nearly uniform in that region as regards the west-to-east direction, but it furnishes a reminder of the close association which we must expect to find between slight changes in temperature distribution and in the direction and force of the wind.

4. SOUNDING OF APRIL 29, 1908.

Northwesterly current in the upper layers crossing a lower current from the southwest.

This is the example of which the details of the working are shown in Table 4, and it is one of great interest, because it is characteristic of the advance of a well-developed cyclonic depression from the westward. It has long been recognized, by seamen and other observers of weather, in observations of upper clouds which are seen to be moving from the northwest while the surface winds are coming from the southwest. It is one of the surest signs of the rainfall which occurs in the front of a cyclonic depression. The table already given shows the values of $\Delta_N p$ and $\Delta_W p$ for each kilometer level, and the values of $\Delta_N \theta$ and $\Delta_W \theta$ computed from the changes in the pressure-differences for successive kilometer steps.

We may note here an ambiguity of notation, which we ought to find some means to remove, and which ought at least to be made clear. In the table [Table 4] Δp and $\Delta\theta$ are used to indicate the *slope* of pressure and of temperature in the two directions N. and W. Thus in the table, when Δp or $\Delta\theta$ is positive for a given direction, it is to be understood that it represents the *fall* of pressure in that direction. But the usual convention of the differential calculus is that an *increase* in the quantity represented is indicated by a positive value of the difference. The ambiguity arises from the use of the convenient symbol Δ to denote the difference, while the meteorological practice is to think of gradient as represented by downward slope. I have not found any convenient new symbol to use instead of Δ to indicate a negative difference, so the ambiguity remains for the present, though I feel that an apology is due for it.

In order to present in a table the corresponding values of Δp and $\Delta\theta$ for the same level, I have taken the means of the two values of Δp for the top and bottom of the kilometer to which $\Delta\theta$ refers. This practice is, perhaps, rather doubtful, but except in Table 6 it has been followed in the tables already given, so I adhere to it in this one.

Converting by simple inversion the figures for Δp and $\Delta\theta$ per 100 kilometers into distances along the axis of the intercepts of the next higher isobar and isotherm, respectively, we obtain the following:

TABLE 8.

Height.	Distance of next higher isobar.		Distance of next higher isotherm.	
km.	*km.*	*km.*	*km.*	*km.*
5-6	84 S	143 W	60 S	102 W
4-5	109 S	263 W	64 S	50 W
3-4	141 S	2,000 W	135 S	132 W
2-3	131 S	526 E	244 N	125 W
1-2	141 S	312 E	93 S	909 E
0-1	200 S	232 E	270 S	222 W

In this table the gradual conversion of a southerly component into a northerly component associated with higher temperature to the westward is very noticeable.

It will be seen that the isobars above 4 kilometers are, roughly speaking, at right angles to those in the lowest kilometer, which is, of course, in accordance with the wind observations; but that the isotherms, with some fluctuations, particularly in the second kilometer, are similarly arranged at the top and at the bottom. That is to say, the upper winds are flowing from the northwest with the higher temperature on the southwest side, while the lower winds are moving transversely from the southwest with a distribution of temperature parallel to that of the upper air, but in this case the isotherms are across the wind.

These results are represented in figure 4, which was originally drawn to the same horizontal scale as the larger chart of the Daily Weather Report, and it is clear that in the lowest stage the columns of warmer air brought in by the southwesterly current are being carried underneath the parallel columns of the upper current. Up to 4 km., where the wind has become westerly, we have a distribution which produces the same effect. The wind is always carrying warmer air under colder air, and as, by Proposition 1, a southerly current tends to thicken

and a northerly current to give way, the pushing under of the warmer air becomes more effective, until instability occurs and rainfall sets in. The irregularities which are

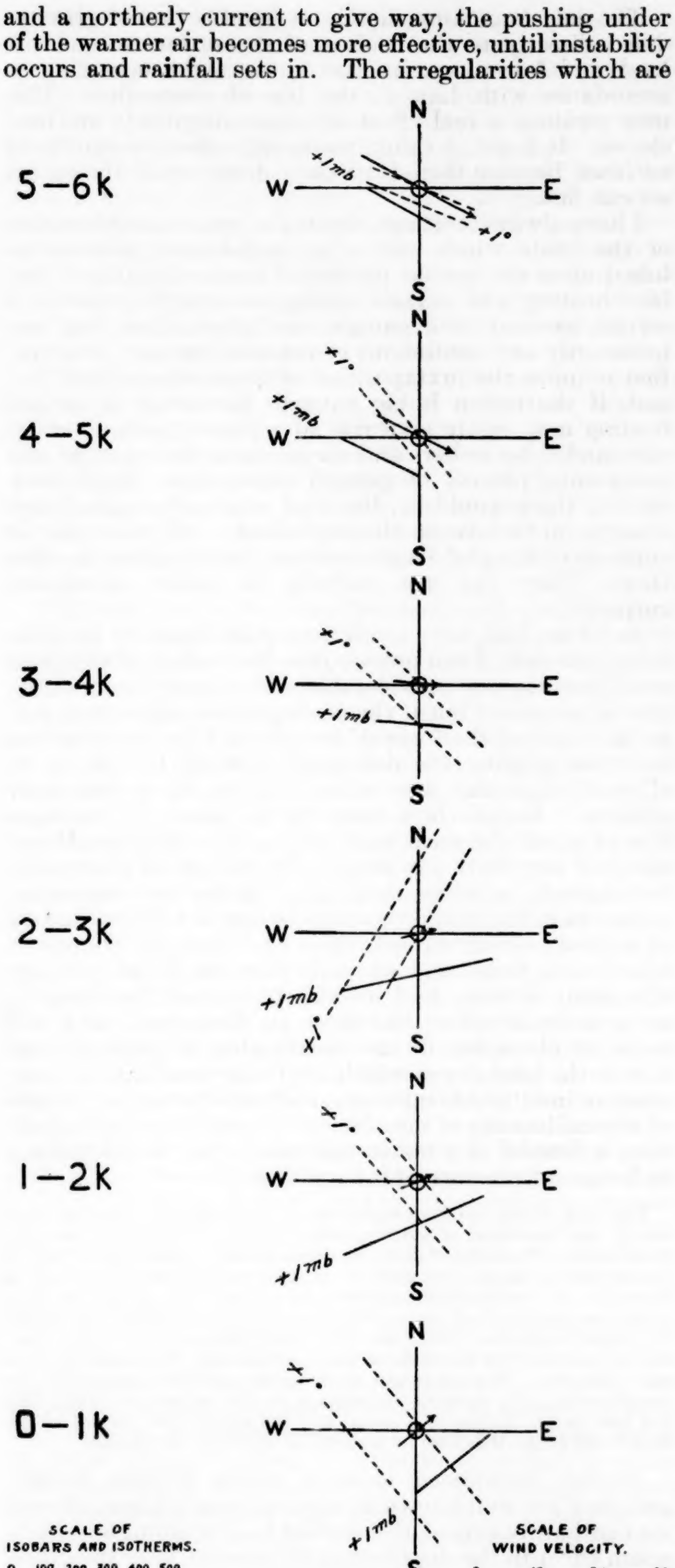

FIG. 4.—Pilot balloon sounding, April 29, 1908. Northwest wind over southwest: characteristic of an advancing depression. The arrow shows the direction and velocity of the wind; the full line, the position of isobar *next above* that which passes through the station. The dotted line through O shows the isotherm passing through the station; the parallel dotted line, the isotherm for *one degree higher* than that of the station.

shown in the distribution of temperature are probably due to previous convection.

We have here, therefore, the assurance of rainfall conditions as the southwesterly wind pursues its course under the northwesterly in front of the approaching depression. The rainy condition of that part of a depression is thus directly accounted for.

The characteristic rainfall of a cyclonic depression is generally associated with a general convergence of the surface isobars, but this hypothesis is difficult to follow into details, because the convergence is general over the area, while the rainfall is local. The analysis of the conditions of the upper air here set out shows that there is good reason for rainfall in the upper layers, to which the doctrine of general convergence can not safely be held to apply.

To the examples which are taken from Mr. Cave's work, I may add one for October 16, 1913, which was reported to me by Mr. J. S. Dines in connection with his work for the branch meteorological office at South Farnborough.

On that day, at Pyrton Hill, where the sounding was made, there was a sudden change of wind between 1,100 and 1,500 meters height from a reasonably steady wind from nearly due south into one almost as steady from due north, the change being accomplished within half a kilometer. The analysis in this case shows for the layer between 500 and 1,100 meters a temperature distribution in isotherms nearly north and south with the warmer air on the east, and above 1,500 meters an entirely different distribution with isotherms nearly east and west, and cold to the northward. The intermediate layer, 400 kilometers thick, showed a very rapid increase of temperature to the west—as much as 7° C. per hundred kilometers.

The complete arrest of the northerly current and production of a calm by the annihilation of the gradient between 1,100 and 1,500 meters is very remarkable, but nevertheless a real fact. The accompanying temperature difference is probably due to a strong temperature "inversion" at a height of about 1,500 meters at the place of observation and of 1,100 meters at a place 100 kilometers distant to the west. On that occasion it lasted for some time, as it was found an hour afterwards by a second balloon; but it must be remembered that it was a region of no velocity, and therefore the relatively warm and cold airs were not moving. In order to get them away, either convection must take place or a gradient must be created.

Proposition 6.—The general circulation of the atmosphere in the Northern Hemisphere.

The reasoning in this proposition is more general in form than that of the foregoing propositions. The extension of our knowledge tends more and more to strengthen the conclusion that the proximate cause of the variations of pressure in the region of the British Isles must be looked for in the layer at a height of about 7 to 9 kilometers; it is the layer of maximum wind velocity just under the stratosphere, and it is also the layer within which must be located a rapid transition of slope of temperature. Below it, as set out in Lemma I the slope of temperature follows the slope of pressure; above it, the slope is in the opposite sense. The mechanism by which the changes of pressure are produced is unknown; but this much is apparently true, that within the layer referred to, the relation between the pressure and temperature of the air at two places on the same level is that of adiabatic expansion. Above the critical layer where this relation holds, the air in the high-pressure area is "too cold," and below it, for 5 or 6

kilometers at least, it is "too warm."[5] We may suppose that air becomes "too warm" by the dynamical warming of downward convection, and, perhaps, also that it becomes "too cold" by piling up under the stratosphere and readjustment of the several layers within the stratosphere, so that pressure on the sample which causes the bulging is reduced, while that over the surrounding regions is increased.[6] Radiation is left out of account—whether rightly or wrongly, it is not possible at this stage to say.

The motion of the critical layer is on the average from west to east, but not invariably so, and apparently the temperature relations which have been described are not dependent upon wind direction. Other phenomena, so far as they have been observed, seem to indicate a similar symmetry, but there is no sufficient evidence for supposing that the phenomena are necessarily centered locally. In fact, according to the distribution of isobars at 4 kilometers computed by Teisserenc de Bort (Lemma II), the average motion does not differ much from a circulation round the pole which, once set up, might be persistent with little change if it was everywhere adjusted to the barometric gradient. The actual motion, however, certainly does change, and is, in fact, constantly changing.

Let us consider the conditions of Teisserenc de Bort's average isobars and the forces which are available to produce the perturbations of a supposed original circumpolar circulation indicated thereby. I have already remarked that, for such a circulation as that represented by Teisserenc de Bort, the isobars for 4 kilometers may fairly be accepted as applicable at 7 kilometers also, because the changes of pressure difference between 4 kilometers and 7 kilometers are in ordinary circumstances very slight.

Taking the average map for January, it will be noticed that the isobars at 4 kilometers are clearly not circles round the pole. If they were so, a steady circulation would be a natural conclusion. It has been already postulated in Lemma II that they are in reality indented ovals or approximate figures of eight with the lobes over the Asiatic and American Continents and the inward bends over the two oceans. I purpose considering, first, the effect of convection as a possible cause of the deviation from the circular shape. The shape which we have to explain is exactly opposite of that which is often shown on synchronous charts of the distribution of pressure at the *surface* of the Northern Hemisphere in winter, and which has "highs" over the continents and "lows" over the oceans. I remark in the first place that, to derive the figure-of-eight shape from the circular shape, one can not rely simply upon the nutation of a west-to-east circulation round the pole; one must superpose either a pair of anticyclonic systems, elongated north or south, over the oceans, or a pair of cyclonic systems over the continents, of which we can at present only determine the southern portions; or we might arrive at the actual shapes by adjustments of both kinds. If we assumed positions for the original circular isobars, it would be a simple matter to give numerical values of the superposed anticyclones or cyclones. But the circumpolar circular isobars are hypothetical, and, at the present stage, the numerical work indicated would be unremunerative. Let us assume, however, such an initial circumpolar system, and consider the physical forces which would disturb its motion.

[5] See Journal Scottish Met. Soc., 1913, loc. cit.
[6] See a note on the Perturbations of the Stratosphere in Publication 202 of the Meteorological Office.

The only force immediately at hand is that of gravity, due indirectly to the cooling of the surface air on the land and frozen sea in the Arctic night operating in accordance with Law 3, the law of convection. This may produce a real effect of some magnitude on land slopes. It is not, I think, necessarily effective over level surfaces, because there is no slope down which the cooled air can flow.

I have always hesitated about the common explanation of the trade winds and other well-known phenomena based upon the reverse process of surface heating. Surface heating and surface cooling necessarily produce a certain amount of expansion and contraction, but not necessarily any continuous convection current. Convection requires the juxtaposition of warm air and cold air, and, if the region is big enough, the result of surface heating may easily give rise to a heated volume of air surrounded by isobars and air currents that prevent any continuous process of general convection. Local convection there would be, but that need only extend high enough up to take up the day's heat. All the main air currents of the globe have pressure distributions to guide them. They can not usefully be called convection currents.

So, if we had, say, a million square miles of level ice round the pole, I can not see that the cooling of that area need produce any considerable effect upon the distribution of pressure; but if the cooling takes place on slopes, we at once get the force of gravity to help, and one can no more suppose the downward flow of the air to be stopped than the flow of a river to be permanently arrested. Hence there must be in winter a continual flow of air off the great land areas of the Northern Hemisphere if they have any slope. The air fall off Greenland, for example, must be enormous. Every description by explorers in the Antarctic seems to support the suggestion of a great cold-air cascade from the Antarctic continent. How much flows, and where it flows to, I can not say; ultimately it must find its way to warmer latitudes by some route or other; but these air flows must be a real cause of alteration in the distribution of pressure, and it is to the land slopes which are losing heat that we may trace an indubitable influence, and therefore a disturbance of the uniformity of circulation. Apart from compensation, a flow-off of 1 meter thickness of air would mean a reduction of pressure of 0.1 millibar.

The facts which are here represented are sometimes taken as indicating the formation of anticyclones over the Arctic and Antarctic land areas. When those areas are represented by plateaus 10,000 or 15,000 feet in height, the surface anticyclone may become merely a hypothetical construction supposed to occupy the space which is really occupied by land and not by air at all. To a considerable extent the great Asiatic and American anticyclones depend upon the reduction of observations to sea level under conditions which can have no real existence. The mountain slope might possibly operate, in the maintenance of a cyclonic circulation in the upper air, much like the hole in the bottom of a basin, and the actual land surface at the high level might therefore be a region of cyclonic circulation.

Similar phenomena must of course happen locally, and they are well known in mountainous regions, though we can hardly expect the smaller local examples to show much effect in the distribution of pressure over the globe.

But we may assume that cold land slopes in winter are the cause of a constant abstraction of air from the lowest layers of the atmosphere in those regions. The cold air flows away by gravity, and since the *surface pressure* is apparently still maintained, the efforts to redress the loss of air have to be carried out in the upper atmosphere and in accordance with its laws; conse-

quently we should expect to find a cyclonic circulation in the level in which the replacement is taking place. The cyclonic circulation may operate to prevent the pressure being made up overhead, but it can not prevent the cold air from flowing downhill unless the reduction of pressure is enough to reduce the density by as much as the low temperature increases it, and this is a difficult task, for near sea level it takes more than 3 millibars loss of pressure to make up for a single degree loss of temperature.

Hence we may suppose that the constant drainage of the land areas would result in the superposition of a cyclonic distribution at high level over them, and the continental lobes of Teisserenc de Bort's isobars for the upper air may well be due to this cause.

But the cause is obviously a very variable one, depending upon the distribution of cloud and other circumstances. Statistically, its effect upon the circulation of the upper air is to exaggerate the pressure gradient for westerly winds over the Temperate Zones of the continents, and to diminish the gradient northward. Thereby we introduce into the circulation local accentuation of current, which must be disposed of by some dynamical process.

The next step in the consideration rests upon the fact that by superposing a cyclonic depression upon the circumpolar circulation we displace a part of that circulation to the southward and reduce the northern part. Taking the case of Teisserenc de Bort's map for January, the westerly run of isobars over America and Asia is about 10° to 20° of latitude lower than over the oceans, and these two positions of westerly circulation have to be connected by isobars which cross the parallels of latitude, and therefore have a south-to-north and a north-to-south component respectively. Therefore, they can only be maintained persistently under the conditions set out in Proposition 1. Now, it has been shown in the discussion of Proposition 1 that permanence of a quasi-steady character might be realized in the case of an anticyclonic ridge having a south-to-north current on its western side, and *vice versa*, provided that momentum was being taken out of the westerly circulation in order to provide a slight eastward deviation from the isobars setting to the north. Such a case would be fairly represented by the deviation from circular isobars shown over the oceans on Teisserenc de Bort's map for January, and hence the form of those isobars may be arrived at by the influence of a steady flow-off of air down the land slope of the Arctic regions and the steady deviation of the wind from the direction of the southwest to northwest isobars on the western sides of the oceans in consequence of the momentum of the westerly circulation.

Meanwhile, what happens to the cold air which has run off the land areas? That has to be steered about by the distribution of pressure in the upper air as modified by any special peculiarities of temperature in the lower regions, and all sorts of complications may arise from this cause. So far as it goes, its density tends to set up high pressure over the regions which it covers, and so to make a slope of pressure southward and cause easterly winds on its southern side. Whenever in a mass of air temperature-fall is in the opposite direction to pressure-fall, great change in the horizontal distribution of pressure underneath is the result, and many of our local variations of pressure may fairly be attributed to the reactions which these cold masses of air offer to the attempt (in the end futile) on the part of the upper air to steer them round the pole from west to east. By their eastward motion these masses of cold air are always reminding us that if left to themselves, without the overpowering guidance of the pressure distribution of the upper air, they would form a circulation round the pole in opposition to the circulation of the upper air, with which they are in perpetual conflict.

TURBULENT MOTION.

In the study which has been the subject of the foregoing pages we have always considered the motion of the air to be regulated by a distribution of pressure balanced by the rotation of the earth, except in regard to the surface layer and one other suggested exception when the momentum of the general westerly circulation was invoked. It should here be noted that by this limitation to what may perhaps be called "great circle motion," we are considering almost exclusively the circulation above that half of the earth's surface which is north of the northern tropic and south of the southern one. There is another section of meteorology which has to deal particularly with the region between the Tropics, where the beginnings of tropical revolving storms are to be found. These storms, which have a diameter of some hundred miles or more, as well as the tornadoes which have a diameter of perhaps a quarter of a mile, belong to the subject of turbulent motion, with which the eddies and whirls that are produced by obstacles on the surface of the ground are also associated. All these phenomena of turbulent motion, important as they sometimes are in real life and death, must be treated in a manner different from that of the present communication.

BIRKELAND'S THEORY OF THE ZODIACAL LIGHT.[1]

[Dated Weather Bureau, Washington, D. C., May 1, 1914.]

Birkeland finds that several of his experiments[2] with a magnetized, phosphorescent terrella in a large vacuum chamber, furnish phenomena which serve him as a starting point for an explanation of the zodiacal light and the gegenschein.

The position of the zodiacal light has now been definitely shown to be closely related to the position of the solar equator, rising and sinking with it, and is not so immediately related to the ecliptic as former general opinion held it to be. One of the most significant, and heretofore unexplained, characteristics of the zodiacal light is the pulsatory character of the variations in its brightness or intensity, and in its shape. These pulsatory changes appear to an observer to be akin to those shown by the aurora and by terrestrial magnetism, and have been correlated with pulsatory oscillations in the terrestrial magnetic field. There is no lack of impeccable observations and records of this pulsation in the zodiacal light, witness writings by Humboldt, Birt of Kew, George Jones of the United States Exploring Expedition to Japan, and Birkeland at Halde, Kaafiord, and Khartum. Evidently an adequate theory of the zodiacal light must account for this feature of it. Birkeland therefore thinks "it very probable * * * that the zodiacal light must be primarily occasioned by electrical phenomena."

Birkeland regards the sun as a great magnet, having a "magnetic moment of the order 10^{28} or about 150 times as great as that of the earth," and that its magnetic equator is essentially coincident with its heliographic equator. Further he finds no good reason for supposing that the sun's magnetic axis is not coincident with its axis of rotation.

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[1] The Norwegian Aurora Polaris Expedition, 1902-1903. V. 1, sec. 2, chap. 5. Christiania. 1913. f°.

[2] Described in "The origin of worlds." By Prof. K. Birkeland, Sci. Amer. suppl., Nos. 1957, 1958. New York, July 5, 12, 1913.

Constant rays of corpuscle-currents composed of atoms, molecules, and electrons are continuously given out by the sun, but apparently these rays are of two kinds: (1) Those of a somewhat less stiff magnetism, which are the rays continually given off by all portions of the sun but probably most strongly from the neighborhood of the heliographic equator; and (2) the very stiff corpuscle rays that radiate in short periods from the portions in greatest activity, viz, at and about the sun spots. The constant, less stiff rays, are less penetrative through matter, and probably come from lesser depths in the solar atmosphere. The very stiff rays from the sun spots are those which it is supposed specially occasion magnetic storms upon our earth.

Birkeland has investigated, experimentally, the behavior of these corpuscle-rays in the magnetic equator of a magnetic globe, and he feels justified in expecting to find that on repeating his previous experiments and using his largest discharge box, he will secure a perfectly flat ring of light 30 centimeters in diameter about the 8-centimeter globe. This will be with a difference of tension of only 700 volts between the globe and the positive pole, and a current of 21 amperes. With a low magnetizing current the ring is broad and small in extent, and when there are slight irregularities in the surface of the globe luminous rays are seen proceeding from the magnetic poles in addition to the luminous ring about the magnetic equator. If the surface is highly polished there is but the luminous equatorial ring. At times this equatorial ring was distinctly divided by a dark circular band into two concentric rings.

When polar rays were also visible they showed deflections equatorward, and the resemblance to the solar corona of May, 1901, became rather striking. In this connection he promises to conduct further experiments wherein he expects to secure even more perfect resemblances between experiment and nature.

Now he finds, mathematically, that—

If radiation starting from the surface of a sphere in the plane of the magnetic equator, and only subject to the magnetic influence of the magnetic field of the sphere, reaches a distance from the center greater than 2.414 times the radius to [of] the sphere, the radiation will not be able to return to the sphere but will pass on toward infinity.

This result is independent of the magnetic moment of the sphere and the stiffness of the rays, but presumes the sphere uniformly magnetized or to have a magnetization which is a function of the distance from the center. His experiments make it—

* * * very possible from a physical point of view, that a ring of radiant matter has been formed round the magnetic equator of the sun, the dimensions of this ring being greater than those of the earth's orbit. [We are here dealing with] corpuscular rays of very great stiffness * * * which partially consist of atoms and molecules, and not merely of electrons, thus * * * the radiant matter in thick layers is both slightly luminous and capable of absorbing and scattering solar light.

Let us now see how we can explain the observed characteristics of the zodiacal light, by supposing that in the sun's equatorial plane there exists a flat ring of radiant streams of matter, consisting principally of primary rays and streams of atoms from the sun, and perhaps also of secondary rays emitted from cosmic dust moving in the same plane and which are irradiated by the primary beams from the sun.

This theory resembles somewhat both the exploded one of Mairan (1731) and that now known as the meteoric theory. In equal degree it resembles that put forward by Jones after discussing his own observations, viz, "the hypothesis of a nebulous ring with the earth for its center." But really Birkeland's theory combines the advantages of the earlier theories and also explains phenomena of the counterglow (gegenschein), and pulsations of the zodiacal light, both heretofore unexplained.

As the earth advances in this assumed ring of radiant matter that surrounds the sun, the magnetism of the earth will sweep away the corpuscles of radiant matter from a space or cavity about it. This cavity is probably not the regularly shaped ring supposed by Jones. The experiments with the terrella show how the stream of corpuscles from the sun will be deflected when they sufficiently approach the earth, in such a way as to readily explain the brightness in the east before sunrise and the brightness in the west after sunset. In the latter case, we are looking into the deep layers of radiant matter lying in the sun's magnetic equator where therefore we see the brightest glow, and the brightness disappears at the boundary formed where the rays spread out to pass around the earth or below its magnetic equator.

From analogy with the terrella experiments, it may be concluded that after passing around the earth the rays will gather into a second sectional line (second line of precipitation) where, however, their density will be much less although still considerable. The concentration in this second line is always greatest when the magnetic axis of the earth (terrella) is perpendicular to the cathode rays, but the position of the line is always approximately on the magnetic equator of the earth and the brilliant origin of the line is always close to the point opposite to the location of the cathode (the sun). Brorsen had come to the conclusion that at both the vernal and the autumnal equinoxes "the brightest part of the gegenschein is directly opposite the place of the sun, so that a calculation of the greatest light frequently coincides to a degree with the point of opposition to the sun," and it appears that all accurate work since his confirms this and other conclusions made by him.

Now, at the time of the equinoxes the "second sectional line" of the corpuscle rays passing around the earth should be most strongly marked and it would lie in the earth's magnetic equatorial plane at a point about 180° from the sun, and also somewhat in the ecliptic or near the sun's equatorial plane. At this season we shall see the points of intersection of the corpuscle rays, the "second line of precipitation," lined up with the sun's magnetic equatorial ring of radiant matter, and which we assume extends beyond the earth's orbit. When regarding this "second line" we see into a considerably thicker stratum of the radiant matter opposite the sun, therefore perceive more diffused light; this increased quantity of diffused light along the "second line of precipitation" may be regarded as the origin of the gegenschein.

Spectrum analysis of the zodiacal light shows it to be essentially sunlight. Occasionally the auroral line is seen superimposed on the zodiacal light spectrum. Birkeland, though accepting analogies guardedly, finds that the known diffusion of light even on the very clearest days, and that his own observations (see below, p. 211) of what he concluded were daylight auroral rays scattering the sunlight and therefore appearing as pulsating daytime clouds, together with researches into optical conditions of electrically luminous gases and vapors by Ladenburg and by Wood, all indicate that "there is comparatively a very large number of dispersion electrons [in the radiant solar matter] that can take up and be in resonance with the light waves from the sun, and that *possibly here, too, this number of dispersion electrons is proportional to the enormous electric current intensity that*

emanates from the sun in the manner here assumed." It is not improbable that the great mass of radiant matter into which we suppose we look when observing the zodiacal light, is capable of diffusing enough sunlight to produce the luminosity of that phenomenon.—[C. A., jr.]

A POSSIBLE CONNECTION BETWEEN MAGNETIC AND METEOROLOGIC PHENOMENA.

By KRISTIAN BIRKELAND.

[Reprinted from Miss Jessie Muir's English text of "The Norwegian Aurora Polaris Expedition, 1902-1903." v. 1, 2d section. Christiania. 1913. p. 449-450.]

93. If the view we have maintained is correct, namely, that the magnetic storms are due to corpuscular rays that are drawn in in zones round the magnetic poles, where they pass directly down into the atmosphere of the earth, it is clear that these rays, especially in the upper strata of the atmosphere, must be assumed to produce a strong ionisation in the air. In our expedition of 1902–03, atmospheric-electrical measurements were made, which will be gone into later on; but it may be remarked here, that the result of these measurements showed that the "Zerstreuung" of the air at those stations averaged about twice as much as in Christiania, indicating that the air up there is considerably more ionised than in lower latitudes. In an expedition which I made in company with my assistant, Mr. Krogness, to Kaafiord at the time when Halley's comet crossed the sun's disc in May, 1910, I had an opportunity of studying this matter more closely.

Instead of, as before, making the measurements at places that are at no great height above sea-level, I on this occasion investigated it at my old aurora observatory on the top of Haldde Mountain, about 910 meters above the sea. Here there proved to be sometimes tremendous variations. On the 20th May, for instance, values were found that went up to about 500 times the normal. Unfortunately the attempt was interrupted in the middle of these measurements; but I had an opportunity of making insulation-tests twice at that time, which proved there was no perceptible leakage. If we can demonstrate this circumstance with certainty, we presumably have before us a phenomenon that is closely connected with the peculiar light-phenomena that Lemström discovered in 1882–3 on a mountain-top at Sodankylä.

There is no doubt that such strong ionisations will have a very great influence upon atmospheric conditions, especially upon the formation of clouds, and must thus be assumed to be a meteorological factor of no small importance, especially for the districts in the vicinity of the auroral zone. I am of the opinion that this is a very important connecting link between terrestrial-magnetic and meteorological phenomena. I have therefore recently submitted to the Norwegian State authorities, a suggestion that a permanent up-to-date magnetic-meteorological observatory be established upon the top of Haldde, for the purpose, if possible, of throwing light upon these interesting and meteorologically important matters.

There was another phenomenon, striking examples of which we had the opportunity of seeing on this expedition in May, 1910, namely, the formation of what may be called auroral clouds. In addition to the usual polar bands, which in a clear sky, could very often be observed in the form of several evenly luminous arcs, of which, however, *one* was especially conspicuous, exactly similar to parallel auroral arcs, we very frequently found formations of cirrus clouds, which exhibited the most perfect agreement with various auroral formations. Several times we had capital examples of the manner in which such clouds are formed, how drapery-formations appeared in a short time, exactly in the same manner as an auroral drapery. The first observer, who has called attention to this very interesting fact seems to be Adam Poulson [Paulsen].[1] As far as I know, no one has, however, studied this phenomenon in connection with simultaneous magnetic registrations at the same place. This we had the opportunity of doing, and the very interesting fact came out, that the formation of these clouds was always accompanied by simultaneous magnetic storms and earth-currents; and there thus appears to be no doubt that these are direct cloud-forming effects of the same rays that occur in the auroral phenomena. From this it seems, that these cirrus-clouds are directly formed by the corpuscular rays which we suppose to be the cause of magnetic storms and aurora. The first hypothesis that one naturally might form as to this phenomenon is, that the clouds are due to water-vapor brought to condensation by the ions formed by the impact of negative rays. It is, however, also a probability that some of the observed "auroral clouds" are not real clouds, but merely a very strong concentration of corpuscular rays, which in the case of darkness might appear luminous; in the daytime the concentration of corpuscles should have the effect of making the places where they occur less transparent, and able to diffuse light, and thus become visible. In such a way also possibly certain faint polar bands observed in the polar regions might be explained. According to circumstances these concentrations may disappear, or perhaps give rise to real clouds.

[1] Paulsen, Adam. Wolkenbildung durch das Nordlicht. (Aus einer Mittheilung an die k. dänische Akad. d. Wiss., 1895.) Meteor. Ztschr., Wien, 1895, 12.Jhrg. p. 161-169.

RADIOTRANSMISSION AND WEATHER.

By A. H. TAYLOR.

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In a previous paper on this subject[1] the writer submitted evidence which seemed to show that unusually good radiotransmission across long overland distances at night is preceded the day before by generally cloudy conditions prevailing in the region across which the nocturnal good transmission takes place.

The evidence presented in that paper has been greatly strengthened by subsequent observations. In particular it may be mentioned, that out of some 60 cases of good transmission studied since September 24, 1913, 44 have followed a generally cloudy condition over the area in case, while of the other 16, a majority have occurred during the shortest days of the year, when the hours of sunlight in the latitude of Grand Forks, N. Dak., are relatively few.

Before discussing the bearing of this evidence on the idea of the reflection and refraction[2] of electric waves by ionized layers of the earth's atmosphere, it will perhaps be well to examine some of the data collected at this station since September 24, 1913, for evidence of a somewhat different character.

In commenting upon the previous paper, the editor of the Electrical World suggested that the effects noted

[1] Electrical World, Aug. 30, 1913.
[2] Dr. Eccles, in The Electrician, Sept. 27, 1912, and Sept. 19, 1913.

might have been indirectly due to general cloudiness, inasmuch as this would usually bring about some rainfall and would therefore probably reduce the ground absorption which is thought to be much larger in overland than oversea transmission. Fortunately the weather during the fall of 1913, especially during the months of October and November, was of such a nature in this part of the continent as to make it possible to settle this important question. The height of the aerial at this station is but 85 feet, so that the nearest of the Great Lakes stations do not usually make themselves heard until after dark. Nevertheless, during a period of over a month in which no moisture whatever fell in northern Minnesota the stations at Port Arthur, *VBA*, and Duluth, *WDM*, were heard as early as 4:30 p. m. on several occasions. Subsequent comparison of weather reports showed that in each instance the intervening region had been very cloudy. In spite of the fact that during this period no rain fell, or even snow until about December 1, there was a great deal of cloudy weather over northern Minnesota, and hence especially close attention was given to the transmissivity from *VBA* and *WDM*. In 80 per cent of the cases of very good transmission from these stations to this one (*9YN*) the preceding day had been very cloudy in this region. The effect of moisture on ground absorption is here eliminated. I am therefore forced to conclude that the effect of alterations of earth absorption are entirely overshadowed by the larger favorable influence of preceding cloudiness. Incidentally these experiments showed that the normal day absorption on clear days in this region is very large. This is supported by the fact that our own signals sent on a 500 meters wave with 7-amperes aerial current were but fairly received just before dusk in Minneapolis at the North Central High School with a 100-foot aerial, whereas less than an hour later they were repeatedly picked up by Mr. Keith Russell on a 70-foot aerial in Toronto. The first distance is 300 and the last 1,000 miles.

It has occurred to the writer to analyze data at hand for the possible influence of barometric pressure on transmission. The weather maps corresponding to the days preceding the evenings of observation were examined and 24 were found which indicated that rather low barometer readings had prevailed in or near the areas across which transmission had been studied. Of these only two were found to correspond with records of bad transmission, while the others all corresponded to records of good transmission. Inasmuch as the weather maps do not arrive here until the day after the transmission records are made, it is not possible for the observer to be prejudiced. Conclusions as to good or bad transmission were based on observations on Sayville, N. Y., call *WSL;* Arlington, Va., call *NAA;* Key West, *NAR* (1,800 m.); Wellfleet, Mass., *WCC;* San Diego, *NPL;* and the Lakes stations at Milwaukee, *WME;* Port Arthur, *VBA;* Duluth, *WDM;* Sault Ste. Marie, *VBB*. For reasons not at once apparent many stations on the Gulf of Mexico or in the Mississippi Valley are received here with extraordinary clearness. A good many observations were made on signals from battleships in the Gulf and upon Galveston, *WGV;* New Orleans, *WHK;* Fort Sam Houston, *WUJ;* Michigan University, *8XA;* Fort Leavenworth, *WUV*, and others. From the west coast, observations were also made upon Mare Island, *NPH;* Point Arguello, *NPK;* and occasionally upon Victoria, *VAK*. A great many other stations might be mentioned as being heard here when transmission was unusually good. A good many vessels were reported at this station, but it was not often possible to locate them very definitely. Finally, shunted telephone readings have been made on our own signals at Memphis, Tenn., by Brother John Berchmanns, of Christian Brothers College; at St. Louis, by Mr. A. S. Blattermann at Washington University; at Boulder, Colo., by Mr. Strock; and by Mr. H. S. Sheppard at Michigan University, in connection with certain tests to be reported on jointly in a future paper. Several amateurs at points from 600 to 1,100 miles distant have been kind enough to make written reports on the relative strength of our signals, among these Mr. Stockman at Denver, Colo., and Mr. Miller at Bushnell, Ill.

In reference to the influence of barometric pressure it must be noted that areas of low barometer are always more or less cloudy. In order to settle this point it is necessary to consider the cases where the barometer readings were generally rather high over the area studied. Of 18 cases which could be put in this class, 11 showed good transmission and 7 poor. But of these 11 cases of good transmission 4 were reported from the valley of the Mississippi, which the author has reason to believe permits phenomenally good transmission, and 6 were over generally cloudy areas. Of the 7 cases of bad transmission associated with rather high barometer, 5 were over very cloudy areas. The writer does not consider this evidence conclusive, but it might mean that high barometer is unfavorable to transmission. Clear-cut cases for long distances are not easy to find for either the high or the low barometer classes.

On the whole it seems as if the presence of clouds is the controlling factor, modified somewhat perhaps by barometric conditions. Bearing this in mind, it seemed worth while to attempt to find out whether cloudiness would be most beneficial at the sender or at the receiver. Accordingly the evenings of observation were divided as follows:

Weather conditions.	Transmission.	
	Good.	Bad.
1. Senders and receiver both in cloudy area	19	4
2. Senders and receiver both in clear area	7	6
3. Senders, cloudy; receiver, clear	14	3
4. Senders, clear; receiver, cloudy	8	7

From this analysis it seems that few cases of good transmission are reported when both stations have been in the clear area preceding the night of observation and about the same indifferent result is seen when the sender only has been in the clear. On the other hand, when the sender but not the receiver has been in the cloudy, the ratio of good to bad transmissions is about the same as when the cloudiness has been quite general. This ratio is 5 : 1 in favor of good transmission. Cloudiness in that portion of the area of transmission near the sender is evidently of the most importance in favoring transmission. This should have an important influence on the formation of any theory which will take account of the variations of nocturnal transmission as a function of the weather of the preceding day.

It seems to the writer that the most serious attempt to correlate fact and theory in long-distance transmission problems has been made by Dr. Eccles in the two papers previously mentioned. As he points out, the hypothesis of an upper layer of ionized air was suggested by Heaviside in 1900, and the idea of the production of such ionization by bombardment of cosmic dust has been advanced by Dr. W. J. Humphreys [3] to account for the fact that

[3] W. J. Humphreys, Astrophysical Journal, May, 1912.

according to the researches of Newcomb, Yntema, Campbell, and Abbot, there is received from the sky a total amount of light which exceeds the total light from the stars. Dr. Eccles seems to prefer, however, the hypothesis of Prof. Schuster [4] put forward to justify his theory of the diurnal variations of terrestrial magnetism. This would mean a gradual increase in ionization and hence in conductivity with the height, but on the whole a degree of ionization which would create a very great absorption. He points out that a very much smaller degree of ionization would suffice to explain some of the phenomena of long-distance radio transmission.

If the equations of the electromagnetic wave in free space be modified by the addition of a term representing the ionic convection current in the path of the wave, there results an expression for the wave velocity which exceeds that of light in free space. A better way of stating this is perhaps to say that the refractive index of ionized air would be less than unity, just as in the case of thin films of some metals whose refractive indices may be much less than unity for light rays. The effect of a refractive index diminishing with increasing altitude would be to tend to bend the waves back to earth, thus following more or less its curvature.

Dr. Eccles offers the very plausible suggestion in regard to the well-known facts of nocturnal long transmission, that the middle portion of the atmosphere is at night mainly un-ionized on account of the absence of sunlight, but that partial refractions occur at the very high permanently ionized layer. This reflection would not take place during the day, as there would be no very sharp transition from ionized to un-ionized atmosphere. His calculations on the amount of bending of long waves during the daytime show that a distribution of ionization is possible such that these waves, at certain critical altitudes (ranging from 40 kilometers for a 2,000-meter wave to 100 kilometers for a 200-meter wave) would suffer a refraction so abrupt as to be equivalent to a reflection, thus accounting for the possibility of long-distance transmission being better in the daytime with long waves than at night. This has been occasionally reported by Marconi of trans-Atlantic transmission. The writer has taken many observations on the 1,800-meter wave of Key West, on Arlington at 2,500 meters, and on Sayville at 2,800 meters, but on three occasions only, in the month of December, were any of them heard in the daytime at this station. The exception was Arlington, distant about 1,400 miles. The signals were barely audible, and not to be compared in intensity with the 9 p. m. (Central time) time signals. The signals of these stations have always been received here stronger as it became later in the evening. The aerial at this station is, however, not high enough to do long-distance receiving in daylight.

The writer does not consider that the evidence which has been presented in this and the preceding paper is in conflict with the theory of Dr. Eccles. On the other hand, it is in no wise to be explained by that theory, dealing as it does with refractions and reflections at relatively high altitudes. The author is inclined to accept the idea of a permanently ionized upper layer at great altitude; he is even willing to entertain the notion that the ionized middle region in daylight plays an important rôle in determining the generally large day absorption, but he considers that the evidence here submitted can only be accounted for by assuming a reflection at the cloud level brought about by a more or less abrupt alteration in the velocity of the wave above and below this level. It is not the clouds themselves that reflect, as good transmission between here and the Lake district has often been observed on very clear nights provided that the day has been cloudy. It is rather caused by an electrical discontinuity which persists after the clouds which caused it have perhaps long disappeared. It is difficult to believe that the probable degree of ionization by sunlight at the cloud level could be sufficient to be of influence, but so far no other more plausible suggestion has occurred to the writer. If this ionization is appreciable, then the clouds would in daylight produce a discontinuity layer which might persist for some hours after sunset. By the time this discontinuity fades away the ionization in the whole intermediate region of the atmosphere will be reduced so that waves may reach the permanently ionized upper layer and be reflected by it with little absorption. Thus good transmission will continue until the morning twilight. It naturally follows that general cloudiness would be beneficial in daylight. As far as observations taken at this station go, they fully agree with this. Unfortunately the day range of this station for reception of signals is not sufficiently great to settle this point definitely. The fact that cloudiness at the sender (where the radiant energy would without reflection be highly divergent) is more beneficial than at the receiver, seems to lend support to this theory. The theory leaves us without any adequate explanation of the day absorption which Austin has shown to be very regular in oversea transmission at least. We must therefore either assume that the daytime ionization under the cloud level averages much larger than is generally assumed, or that the radiation is divided as follows:

1. A portion reflected from the cloud level, and passing from sender to receiver as between two approximately parallel surfaces, and hence not following the inverse square law of divergence, and not heavily absorbed, since it travels in a feebly ionized medium.
2. A portion entering the middle ionized region and refracted back toward the earth according to the theory of Dr. Eccles. This portion would be absorbed during the day, but very feebly absorbed at night.
3. A portion passing through the middle region and partially reflected at the upper permanently ionized layer. This would be heavily absorbed during the day and feebly absorbed at night.
4. A portion which passes out into space is lost.

It is likely that the second portion is of the most importance in the daytime, while the vagaries of long distance nocturnal transmission are due to combinations at the receiver of the first and third portions. Those rapid variations in the strength of signals (swinging) and the slower fluctuations (fading) so familiar to operators in long range work may well be due to interference effects between these two portions.

The rapidity with which these effects often occur strongly suggests the idea of a violent commotion in the lower levels in the wave path.

Accordingly, daylight transmission over a clear area would be carried on mainly by the second portion, the third portion being heavily absorbed. Daylight transmission over a cloudy area (especially where cloudy at sender and its vicinity) would be reinforced by the first portion.

Nocturnal transmission following clear days would be carried on by the second portion reinforced by the third, both portions being feebly absorbed. Nocturnal trans-

[4] Phil. trans., A, 1907.

mission following cloudiness would in general be carried on by all three portions, but the evidence here presented suggests that the first portion, added to the third, both feebly absorbed, is of great importance.

Since completing this paper the writer has read an interesting account by Nipher, in the Proceedings of the Saint Louis Academy of Sciences, 1913, of local magnetic storms whose origin he believes to have traced to the influence of clouds. He finds also a period of magnetic disturbances coinciding with the well-known twilight fluctuations in radiotransmission. Prof. Nipher suggests a variation in the ionization of the *lower* levels caused by variations in the sunlight as the nature of this influence. There seems to be an intimate connection between these phenomena and the variations in radiotransmission.

Number.	Station.	Longitude.	First Phase.			Second Phase.		
			Arrival.	Maximum.	Principal maximum.	Arrival.	Maximum.	Principal maximum.
		1	2	3	4	5	6	7
		West. ° ′	1912.			1912.		
1	Katmai	155 0	June 6, eruption					
2	Mount Wilson	119 10				June 21, haze. July 1, actinom	July 4	No
3	Washington	77 0	June 10, haze					Aug. 15
4	West Greenland	50 0	After June 15. Before June 21					
5	Iceland	21 52	June 16	Between June 17–July 1	No	July 1–26		
		East.						
6	Algiers	4 0	June 19, haze. June 28–30, actin	July 6	No	July 11	July 11–20	No
7	Heidelberg	8 42	June 20, twilight	July 8–11	No	July 19	July 20–25	No
8	Zurich	8 33	June 23, vapor veil.	July 12				
9	Hamburg	10 0	June 23, twilight					
10	Denmark	10 0	June 23	July 11	Yes; end of July	July 21	July 22; July 28	July 11
11	Pavia	9 10	June 27	July 11	Sept. 15	Absent	Absent	Absent
12	Salo	10 31	June 27	June 27	July 22	July 22	July 23	June 27
13	Ischia	13 50	June 24	July 9–12	No	July 24	July 27	Yes
14	Innsbruck	11 25	June 23	July 6–12, or later	No	Absent	Absent	Absent
15	Potsdam	13 0	June 24–27	July 10–15	Yes; like late summer	July 26	July 26; Aug. 1 (?)	Like July 10
16	Triest	13 50	June 24	July 13	Yes	July 28 (?)		No
17	Donnersberg	13 50	June 28	July 12–16	No	Indefinite (?)	Aug. 5 (?)	No
18	Tetschen	14 15	June 23	July 11–15	Yes	Absent	Absent	Absent
19	Fiume	14 25	June 28	July 15	No	July 24	July 24	Yes
20	Vienna	16 25	June 25–29	July 12–18	Yes; Aug. 1	July 28	July 28–Aug. 1	Yes; July
21	Häfringe	17 19	June 29	July 21	Yes	Absent		
22	Warsaw	21 01	June 26	July 26, after gaps	Yes; Aug. 22–Oct. 1	Aug. 2	Aug. 2–22	July 26–Oct. 1
23	Przegaliny	22 48	June 22 (?)	July 26	Yes	Absent	Absent	Absent
24	Sophia	23 15	June 26					
25	Athens	23 43	June 17	Increasing to Aug. 5	Oct. 1	Aug. 5	Aug. 5	Oct. 1
26	Egypt	31 0	June 28	July 3	No	Aug. 8	Aug. 8	Sept. 9

MAURER & DORNO ON THE PROGRESS AND GEOGRAPHICAL DISTRIBUTION OF THE ATMOSPHERIC-OPTICAL DISTURBANCE OF 1912-13.[1]

In January, 1913, Prof. J. Maurer of Zurich sent out, in his capacity as chairman of the Solar Radiation Commission of the International Meteorological Committee, a circular letter[2] requesting the meteorological institutes and bureaus of the world to compile and send to his commission complete details of observations that would help the study of the great atmospheric opacity which appeared over the Northern Hemisphere in 1912. A large amount of material was received in response to that request, and was placed in the hands of Maurer (Zurich) and C. Dorno (Davos) for discussion. The following paragraphs attempt to summarize the results as presented by the two authors in the paper first cited.

[1] Summarized from: *Maurer, J., & Dorno, C.* Über den Verlauf und die geographische Verbreitung der atmosphärisch-optischen Störung, 1912-13. Met. Ztschr., Braunschweig, Feb. 1914, 31. Jhrg, pp. 49-62.

[2] See Meteorologische Zeitschrift, Braunschweig, Februar, 1913, 30. Jhrg, p. 92.

MATERIAL.

The first step in the discussion was to collect the records of the Campbell-Stokes sunshine recorders for those days of 1912 which yielded well-defined traces. These were compared with the records for the same localities on corresponding days of average or normal years; the best years immediately preceding 1912 were chosen as these standards of comparison. Of course there had been considerable variations in judgment of what constituted the beginning of the daily record-trace, in exposures and in instrumental peculiarities among so many contributing institutions. Particular difficulty arose in endeavoring to estimate the effects of low-lying haze and fog upon the Italian records. Eventually, however, the comparisons yielded a quantity of differences in the times of beginning of each day's record for 1912 as compared with the corresponding data for average years. These differences were then carefully reworked graphically by Dorno.

Then the actinometric and polarization observations were gone over in an equally careful, critical manner. The actinometer records were studied by comparing the daily maxima throughout 1912 with the average maxima for corresponding days and the resulting differences were plotted. In the polarization records the maximum and the minimum values of the antisolar distance of Arago's Point for 1912 were similarly compared with the average values for normal years. Finally all manuscripts and published notes on the sky were carefully compared with the plotted curves; the curves obtained from the sunshine recorders were supplemented by those from the photo-recording station at Tetschen and by the curves from practically all the actinometric and polarimetric observatories of the world. In all 36 such curves were prepared and studied; selections from them are reproduced as figure 1 of the article noticed, but must be omitted here.

RESULTS OF COMPARISONS.

The results of the whole study are succinctly presented in Table 1. This list of phenomena includes, however, only those that may with certainty be ascribed to the eruption of Katmai volcano. So far as the incomplete and variable character of the material permitted, the phenomena have been correlated and arranged to show the sequence of events and the different phases. It was often difficult to properly distinguish the different phases because of locally veiling influences, and also owing to the discontinuous character of the high, bright clouds which formed the principal characteristic of the phenomenon. However, it seems possible to distinguish five phases in the development of the disturbance.

THIRD PHASE.				FOURTH PHASE.				
Arrival. 8	Maximum. 9	Principal maximum. 10	Arrival. 11	Maximum. 12	Principal maximum. 13	CLEARING OFF. 14	NEW HAZINESS. 15	Number.
July								1
July 19–26	Aug. 2	Yes	End of August	Reported	No.	No report		2
		Aug. 15				Sept. 15–Oct. 15		3
								4
July 26	Aug. 7–16	Yes	Sept. 9	Sept. 9	No.	Oct. 1–16	O. 16–25, report stops.	5
Aug. 1	Aug. 3	Yes	About Sept. 10	Ci-st		Ci-st. Sept. 15–Oct. 27.	Oct. 27–Nov. 10, report stops.	6
Aug. 10	Aug. 20	Yes	Sept. 12	Sept. 12	No.	Oct. 9–15	Dec. 20	7
						Oct. 11		8
								9
Absent	Absent	Absent	Sept. 15	Sept. 18	No	Oct. 9–20		10
Absent	Aug. 29	Sept. 15	Sept. 14	Sept. 15	July 12–Aug. 29	Absent		11
Aug. 16	Aug. 8	Absent	Absent	Absent	Absent	Absent		12
Aug. 18	Aug. 18; Aug. 30	No	Sept. 17	Sept. 17	No	Absent		13
Absent	Absent	Absent	Sept. 18	Sept. 22–23	Yes	Oct. 7–23		14
Absent in part	Aug. 28	No	Sept. 12	Sept. 12	No	Oct. 4–Nov. 1	Nov. 6–30; Dec. 19	15
Aug. 18?	(?)	(?)	Absent	Absent	Absent	Gaps to Oct. 17		16
Beginning is absent	Sept. 9	Yes	Sept. 24 (gaps)	Sept. 24 (gaps)	No	Oct. 5–11		17
Aug. 18	Aug. 18	No	Absent	Absent	Absent	Oct. 21		18
Aug. 15, absent in part	Sept. 5	(?)	Sept. 15	Sept. 15	No	Oct. 5–15		19
Aug. 20	Aug. 20	No?	Absent	Absent	Absent	Absent		20
								21
Sept. 12?	Sept. 12	No?	Sept. 29	Sept. 29	Aug. 2–22	Oct. 5–Nov. 4	Nov. 4, Nov. 26, etc.	22
Aug. 25	Sept. 15	No	Not recognizable	Not recognizable	Not recognizable	Not recognizable	Not recognizable	23
								24
Increasing Sept. 1–30	Sept. 30	Aug. 5		Sept. 30	Aug. 5	Oct. 1–31	No change, slight effect.	25
Aug. 23–Sept. 8	Sept. 8	Yes	Sept. 23	Sept. 23	No	Clear, Sept. 30		26

First phase.—Immediately succeeding the first eruption of Katmai on June 6, 1912, the sea was pumice-covered in the vicinity of the volcano, there occurred an ash fall of 30 cm. depth even to a distance of 150 km. (93 mis.), and traces of ash fell at 1,500 km. (932 mis.). Corroding sulphuric acid in the air destroyed vegetation at a distance of 700 km. (435 mis.) and was still perceptible at 1,400 km. (870 mis.).

An unusual haze due to large numbers of condensation nuclei floating at low and intermediate levels was observed at Madison, Wis., on June 9 and 10, at Helena, Mont., and at Washington, D. C., on the 10th. As early as June 8, Madison, Wis., observed and described a very high cloud of vapor traveling rapidly eastward and having all the characteristics of the cloud later more generally observed; but it was broken up like a dissolving jet or stream and had not yet taken on its more compact form. Thus it appears the high, bright clouds were formed immediately upon the first eruption, and they best enable us to follow the course of the optical disturbance in its characteristically WNW–ESE movement. The velocity of the clouds agreed with the observed wind velocities prevailing above North America. Their arrival above Europe was well observed at Heidelberg on June 20–21, at the observatory on the Zugspitze (lat. 47° 25′ N., long. 10° 59′ E., alt. 2964 m.) on June 22, and at Zurich on the 23d. At their front they were so delicate that the Campbell-Stokes recorders were not affected until greater thicknesses of the haze began arriving several days later. Column 2 of the table shows the dates of arrival of the advancing front, and the maximum of the first phase is shown in column 3.

Second phase.—The second wave of the phenomenon appeared over the northern Pacific coast of the United States on June 18. On June 21 it reached Mount Wilson in southern California, thus indicating that it was spreading farther south than did the first phase. Again its first character was that of very delicate, bright high vapor clouds barely able to exert any noticeable influence upon insolation intensities, and it was not until 8 or 10 days later that this element was strongly affected. The wave was characterized by a double crest of but a few days' interval, the second crest being higher [that is, the cloud was denser] than the first.

Third phase.—The third phase, represented by the data collected in columns 8, 9, and 10 of Table 1, might be regarded as the result of superposing phases 1 and 2. The striking peak in the curves for Iceland and many other localities might be said to point to a new eruption if one is disinclined to assume that upper air currents had drifted the masses together and just in this direction. Localities that are least subject to disturbing weather conditions have their principal maximum during this phase instead of the first phase, as did other places.

Fourth phase.—Many stations reported that there were signs of a clearing off in progress during the days just previous to the dates entered in column 11. The dissolution of the high, bright clouds seemed to be well ad-

vanced when they were reinforced by the eruption of August 19 [?].

A sharp drop in the various curves marks the appearance of this new cloudy condensation whose effects continued until mid-October. The time of its final disappearance depends upon the longitude of the respective localities.

Actinometric and optical observations show that a strongly absorptive foreign stratum persisted for some time after even mid-October. It thus becomes necessary when considering the phenomenon as a whole to distinguish between the visible, high, bright, cloudy condensation of hygroscopic origin at altitudes between 10 and 12 km., and the invisible absorbing stratum which consisted of the finest volcanic dust driven farther up into stratosphere levels which are less favorable to the hygroscopic growth of cirrus-like clouds.

The Campbell-Stokes sunshine recorders seem to have clearly demonstrated their general reliability, at any rate, in so far as the principal features of this disturbance were concerned.

Extent and intensity of the disturbance.

It appears that the disturbance of 1912–13 scarcely attained latitudes as high as 80° N. in Greenland, or as low as the Azores in about 40° N., where the Horse Latitudes seem to have called a sharp halt to the spreading cloud. It seems certain that in longitude the disturbance extended as far as central and northern Asia after crossing Europe. Reports from India leave us in doubt as to its further eastward extension, but the low intensities at Mount Wilson August 10–20, 1912, keep this question open. Additional reports from Batavia, Australia, Argentine Republic, and Chile show definitely that there was no general cosmic disturbance affecting the whole globe. So far as it is possible to correlate and compare the various measurements of decreased insolation, they agree with the general characters of the disturbance as outlined above. The intensity of insolation suffered least at such marginal points as Mount Wilson, Cal., and Bassour, Egypt, while the greatest weakening lay near the axis of the "shadow" as at Häfringe, Sweden, and Potsdam-Berlin, Germany.

WAS KATMAI ALONE RESPONSIBLE?

As has just been noted, there is no evidence of any general cosmic disturbance such as must have affected both hemispheres.

It appears certain that there were disturbances preceding the outbreak of Katmai on June 6. Stations in Egypt, Athens, Hungary, Poland, and Häfringe, all lying within narrow longitudinal limits, report disturbances between May 31 and June 6, which lag, weaken, and grow shorter from the south northward. It seems possible to trace small forerunners of this wholly independent pre-Katmai disturbance in the reports from Vienna, Tetschen, Potsdam, Toggenburg (Switzerland), Fiume, Pavia, etc., but it seems advisable not to give these hints too much weight. Some eruption in the Philippines at about this time, though reported subsequently, may here furnish an underlying cause. Stellar photometric work at the Vienna Astronomical Obsevatory was seriously interrupted during the period June 6–12, 1912, and this is certainly to be correlated with those eruptions.

CONDITIONS IN

Dorno's extensive Davos observations on sky polarization, twilight phenomena and Bishop's Ring, show plainly that the more pronounced disturbance endured through January, 1913. He found no distinct recovery of normal insolation intensities at Davos until February 9, 1913. Sky-light polarization, twilight phenomena, and notably the frequent glorious purple afterglows of November and December, 1913, occurrences of Bishop's Ring, and of peculiar glares about the sun, showed that conditions were not yet normal over Europe at the close of 1913.

These conditions emphasize the necessity for compiling and transmitting to the Solar Radiation Commission full reports to the close of 1913, and for continued careful observations through 1914.—[C. A., jr.]

SECTION II.—GENERAL METEOROLOGY.

METEOROLOGICAL OBSERVATIONS IN CONNECTION WITH BOTANICAL GEOGRAPHY, AGRICULTURE, AND FORESTRY.

[Read before the Botanical Society of Washington, April 7, 1914.]

By RAPHAEL ZON, Chief of Forest Investigations.

[Dated, U. S. Forest Service, Washington, May 10, 1914.]

The title of this paper is really more ambitious than its contents. It is far beyond one ordinary man's power to prepare a comprehensive plan for meteorological observations that would meet the needs of botanists, agriculturists, and foresters, especially if this man happens to be only a forester. I hope, however, that these suggestions, meager as they are, may at least result in a discussion of this important subject.

I wish to make it entirely clear that I have no intention whatever to criticize the records as now collected by our own or any other Weather Bureau. First, present methods of gathering and publishing weather data are a result of international agreement and can not be readily changed to suit the needs of any one particular interest. Second, I am not certain that it is within the function of any weather bureau to work up the meteorological data in the manner in which they are needed by botanists, foresters, and agriculturists; its primary duty is to secure original data which can be computed in any form needed by students of plant life. Third, plant ecologists have never to my knowledge formulated any constructive plan for working up meteorological data that would be acceptable to botanists in general. If the present meteorological data are not exactly in the shape in which they can be most effectively used for interpretation of plant life, it is therefore not so much the fault of the meteorologists as the fault of the botanists themselves.

Some criticize the weather records because they do not show the thermal units of heat and the actual amounts of humidity that plants utilize in their life processes; others, because they do not include measurements of a number of physical factors which affect plant life; while still others consider the distribution and location of many weather stations to be inadequate for a proper interpretation of the distribution of vegetation over the country; and so on. But these questions refer to biology, not to climate. There is no doubt but that meteorological observations generally interpret climate from a purely meteorological point of view and ignore almost entirely the biological side. The fault, however, in my opinion, lies not so much in the kind and character of observations that are being recorded as in the manner of their classification, their grouping and computing. Any broad plan for meteorological observations covering a large country, even when viewed from an entirely biological point of view, must necessarily confine itself to observations of such climatic factors as affect only the fundamental processes of the growth of vegetation in general, without attempting to provide data for the understanding of some specific phases in the development of a plant. The latter must always be a subject of special investigation.

Some of the criticisms directed against the present weather records on the ground that they do not show the exact amounts of heat or moisture utilized by plants do not seem to me well founded. For instance, it is true that plants do not make use of the amount of available heat. Even with an exact knowledge, however, of the absolute quantities of heat and moisture which plants receive in a given locality, still we would not know their absolute climatic requirements. Most of the introduced plants tend to retain in their new home their inherited phenological habits. It is well known that the oak and the beech which, in their original home in the Temperate Zone, normally shed their foliage in October and November, on being transplanted to the island of Madeira continue to shed their foliage in these two months in spite of a climate favoring their growth during the fall. Another striking example is found in our Rocky Mountain and Pacific coast Douglas fir. Douglas fir from the Pacific coast when grown in a continental climate does not withstand frosts, while the Rocky Mountain form of Douglas fir does so no matter where it is planted. For this reason even most accurate measurements of heat and moisture would not be of any material help to us in determining the climatic requirements of plants, because we do not yet know to what extent a given species or variety of plant will utilize the available heat and moisture for its life functions.

With our present knowledge of the requirements of the various species, varieties, and biological races of plants for heat and moisture we can only aim to compare the climate of a given locality with the climate of other localities in which the same plants are growing thriftily. For this reason what we need at present are not meteorological data of absolute accuracy, but rather data that will permit of an accurate comparison between the climatic features that are essential to plant life in different localities. The combination of purely meteorological and biological viewpoints in classifying and computing meteorological observations for purposes of botany seem to me absolutely essential. With our present meteorological observations secured at the weather stations, but with a different method of grouping them, it is possible to secure results which would be of value to students of plant life. I shall attempt to indicate here the manner in which the original meteorological observations should be classified and computed in order to make them of value to biologists, and shall cover briefly temperature of the air, precipitation both in the form of rain and snow, relative humidity of the air, wind movement, and barometric pressure.

Temperature of the air.

Mean annual temperature.—It is common to characterize a given locality by its mean annual temperature. This temperature is, of course, important for the general climatic orientation, but has no direct bearing upon plant life.

Mean seasonal temperature.—Another common way of grouping the temperature data is by the four astronomical

seasons, spring, summer, autumn, and winter. This method by seasons is void of any significance for the proper understanding of plant life. It is, of course, ridiculous, for instance, to consider March as a spring month in the State of Maine when the entire vegetation is still in its period of rest, the ground covered with a deep layer of snow, and the temperature below freezing.

Periods of growth and rest.

Properly to understand plant life it is essential to group temperature data by periods of growth and rest. During each of these two periods plants react to temperature of the air in altogether different ways. Aside from the herbaceous vegetation, which during the period of rest is entirely hidden in the ground, trees require different amounts of heat during the period of rest and period of growth. Thus the Siberian fir (*Abies sibirica*), which during its period of rest withstands with impunity the lowest temperatures ever recorded anywhere on the earth's surface, in the spring has its terminal shoots killed at a temperature of 28.5° F. For this reason Siberian fir forms vast forests near the thermal pole, but is killed by frost in the Valley of the Rhine. It is evident that mean annual temperatures, or mean seasonal temperatures, could not throw any light whatever upon phenomena of this character. At some experiment stations, here and abroad, the grouping of meteorological data by periods of growth is in use, but chiefly with reference to some definite phases of development of several of the important agricultural plants. Painstaking computations of such observations is time consuming; it would be a difficult task to attempt to secure them for most plants. Even if it were possible to obtain such observations they would not provide a common, reliable basis for comparing the climatic features essential to plant life in different localities. Thus, the observations upon the temperature data of any given locality should be computed not merely by the period of rest and growth of one or several cultivated plants, but by the general periods of rest and growth of the native vegetation of the locality. In each locality it is possible to determine some climatic features which are especially characteristic and important for the entire natural vegetation of the region. These fundamental characteristics of a given local climate are also of importance for the cultivated plants within the region.

If we exclude the climate of the Arctic region, which, within the United States, is found only at high elevations within the Alpine zone of the Rocky Mountains, Cascades, and Sierras, and in the Appalachian range in the Northeast, and excluding also the subtropical region which is confined to Florida, southern California, Arizona, New Mexico, and areas in close proximity to the Gulf, then we find that most of this country lies within the temperate region of the globe. The temperature records of this temperate region of the United States not reduced to sea level, should be separately computed on the basis of the local normal monthly mean for the cold period, or period of rest, and the moderate period, or period of growth, and in some localities also for a third period, the hot period. The cold period should include, according to Köppen, all months having a normal mean temperature of 48° F. or less; this embraces the period of more or less complete rest of the majority of plants of the Temperate Zone. In the period of growth, or moderate period, should be included all months having a normal monthly temperature of from 49° to 72° F. This last period in the Temperate Zone is that of most active growth and of the ripening of fruits of all kinds. The third, or hot period, in temperate latitudes should embrace months with a normal average temperature of more than 72° F. Where there is a lack of precipitation or irrigation, this means the period of summer rest; when there is a sufficient amount of precipitation, the period of ripening of southern fruits; and when there is an abundance of moisture, the period of subtropical growth.

The division into periods of growth and rest in the Arctic and subtropical regions must probably be made on a somewhat different basis than the division in the temperate region. The cold period in the Arctic region continues practically the entire year, and whatever growth takes place must occur at temperatures at which most of the vegetation in the temperate region is still in a dormant stage. The Arctic and true Alpine plants require for their development a very small amount of heat, but demand invariably a long period of rest, the lack of which is more harmful to them than anything else. In the subtropical region the plants as a rule are entirely indifferent to surplus of summer heat, but require during the vegetative period a certain amount of moisture, and during the cold period do not withstand any great fall of temperature.

The duration of the three different periods—cold, moderate, and hot—must be determined for each locality or region on the basis of normal mean monthly temperatures, not reduced to sea level. The climate of the United States in this respect is well enough known to make it entirely possible to prepare a map in which the localities that are of agricultural importance and having the same duration of these different periods could be grouped. The preparation of such a map for our mountain regions is yet hardly possible, at least with any degree of accuracy, although some attempt may be made even on the basis of our still inadequate information. The map (fig. 1) here presented has been prepared in accordance with the foregoing plan, and represents the first attempt of its kind. The periods of growth and rest shown in the map are based on the mean monthly temperatures for 685 stations given in Bulletin Q of the U. S. Weather Bureau, "Climatology of the United States," by A. J. Henry.

Thus the monthly mean temperatures, if grouped by periods of actual plant activities, are of importance not only to meteorologists, but also to botanists. Their reduction, however, to sea level, which is practiced by meteorologists in their maps for certain studies, is extremely inadvisable for purposes of studying plant life.

In addition to the monthly mean temperatures, the average temperatures by periods of ten days (decades) are also desirable. In any locality such averages are useful to botanists only during certain months; in temperate regions chiefly at the end and at the beginning of the growth period; and in the more southern latitudes during the entire cold period. Since, however, in different localities the 10-day periods are important for different months of the year, an attempt should be made to give the means for all 36 decades of the year. The pentads of Dove are appropriate for more intensive studies.

Aside from the monthly mean temperatures and mean temperatures for periods of 10 days, it is also of importance to have information about the mean temperatures for the period the ground is covered with snow and for the period when the ground is bare. The protective value of snow against injury from low temperatures to herbaceous and low arborescent vegetation, especially winter crops, is well known. The depth of the snow cover is often the determining factor in the

distribution of some of our trees. A species when planted north of its natural range, may grow at first very thriftily and withstand winters without injury as long as it is covered with snow. As soon, however, as its terminal shoots begin to rise above the snow line they are invariably killed. Those which sprout prolifically from the stump renew themselves every year by means of root suckers, and often produce flowers, thus becoming low shrubs.

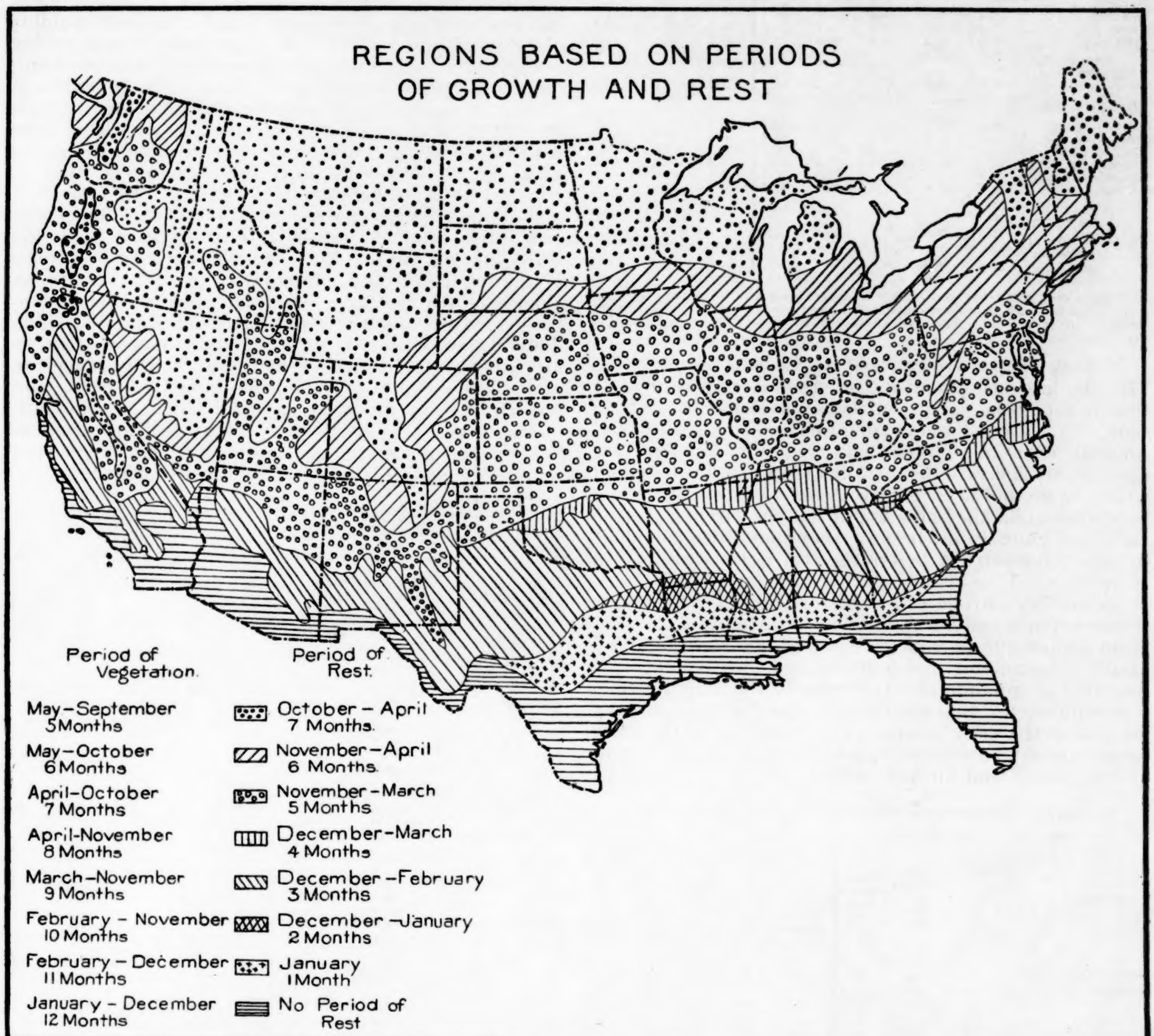

FIG. 1. Vegetal regions of the United States, based on periods of growth and rest deduced from the mean monthly temperatures for 685 stations as given in "Climatology of the United States," by Prof. A. J. Henry, Washington, 1906, Weather Bureau bulletin "Q."

Closely associated with the effect of temperature upon plant growth is the effect of the wind. If there were no winds and air currents, every locality would have its own climate. Winds, however, depending upon the direction from which they come, give the locality, as it were, practically a new climate. Biologically it is very important to know the characteristic features of the climates that are brought to a given locality by winds from outside. For this purpose it is not enough to know only the direction and the velocity of the prevailing winds, but also their temperature and humidity. Thus it is essential, aside from general monthly mean temperatures, to compute also the mean temperature for each period during which certain winds prevail. It is not necessary to compute this mean temperature for each wind but only for the main prevailing winds, since, in regard to their effect upon vegetation, winds from several directions may be grouped together, such as southerly winds, easterly, etc.

TABLE 1.—*Temperature of the air by periods of rest and growth.*[1]

Month.	Average temperature.	For days with no snow on ground.	For days with snow.	For days with easterly winds.	For days with westerly winds.	For the first 10 days.	For the second 10 days.	For the third 10 days.
Period of rest.	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
November	34.5	40.6	30.0	34.7	34.0	39.7	34.5	29.5
December	31.8	34.0	31.6	32.4	28.6	39.7	26.4	29.5
January	28.0	....	28.0	28.2	27.9	31.8	31.3	21.9
February	26.4	....	26.4	25.9	26.4	30.7	24.1	24.8
March	30.4	....	30.4	29.1	30.6	30.2	28.8	32.0
April	47.3	48.4	46.8	49.6	42.6	48.2	48.6	45.5
Average for the rest-period	33.1	39.0	31.5	34.5	30.9	....	....	....
Period of growth.								
May	54.3	54.3	....	57.4	52.2	52.9	54.0	55.8
June	61.2	61.2	....	62.6	60.4	58.6	60.8	64.0
July	64.4	64.4	....	69.3	60.3	60.1	66.2	66.7
August	64.0	64.0	....	67.6	60.4	62.6	64.4	64.9
September	54.9	54.9	....	58.8	51.1	54.1	61.9	48.7
October	48.6	48.6	....	49.5	47.7	51.3	50.2	44.6
Average for the growth-period	57.9	57.9	....	60.4	....	....	....	....
Average for year	45.5	56.3	31.5	....	....	....	....	....

[1] These records, while they were actually made, are given here not as a characteristic of the region in which they were collected, but merely for the sake of illustrating the method of arranging weather data. This holds true for all the other tables included in the statement.

Absolute daily maximum and minimum temperatures.—The absolute maximum and minimum temperatures of the air should be computed separately for days with no snow on the ground and again for days with a snow cover, since the effect of minimum and maximum temperatures upon plants is very different when the ground is bare and when the ground is covered with snow. Maximum temperatures while the snow is still on the ground are too early and undesirable, because they may force the plant to vegetative activity before the real warm weather has come.

Mean daily maxima and minima.—Since for the plants the occurrence and duration of the maximum and minimum temperatures are of more importance than the brief absolute maximum and minimum temperatures, it is desirable to compute also the mean of the daily maxima and minima for the month and also the maxima and minima of the daily means. The minimum of the daily means should be shown separately for days with snow on the ground and for days without snow.

TABLE 2.—*Temperature of the air by periods of rest and growth.*

Month.	Absolute maximum.		Mean of daily daily maxima.	Maximum of daily means.	Absolute minimum.		Mean of daily minima.	Minimum of daily means.	
	For days with no snow.	For days with snow.			For days with no snow.	For days with snow.		With no snow.	With snow.
Period of rest.	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
November	64.2	42.3	39.6	53.4	33.8	14.0	30.2	37.4	21.4
December	55.4	55.4	35.8	46.8	30.9	14.0	27.7	34.0	18.1
January	....	48.2	31.5	41.4	....	11.3	24.6	......	18.5
February	....	44.8	31.3	44.2	....	12.6	22.3	......	18.5
March	....	58.5	35.6	47.7	....	16.7	25.5	......	23.9
April	69.4	68.5	56.5	57.9	32.0	31.1	39.4	39.0	33.1
Average for the rest-period	69.4	68.5	38.3	57.9	30.9	11.3	28.2	34.0	18.1
Period of growth.									
May	74.1	....	62.4	63.9	39.2	....	45.5	45.9	......
June	79.7	....	69.1	68.4	48.7	....	53.1	53.1	......
July	82.8	....	72.5	71.8	50.0	....	57.7	52.9	......
August	80.6	....	72.0	71.4	44.6	....	57.4	53.2	......
September	80.8	....	61.9	67.8	39.2	....	49.3	46.0	......
October	68.9	....	56.3	56.5	32.0	....	41.9	40.6	......
Average for the growth-period	82.8	....	65.7	71.8	32.0	....	50.9	40.6	......
Average for year	82.8	68.5	52.0	71.8	30.9	11.3	39.6	34.0	18.1

Range of temperature.—For plant life the range of the temperature of the air during 24 hours and during more prolonged periods is of great importance. The effect of temperature fluctuation upon plants is well known. Thus a uniformly severe winter will have an injurious effect upon plants adapted to a given climate only when the preceding summer was short or not sufficiently warm or too humid, and the shoots have not had time to ripen. The most injurious winters are not the severest winters, but winters which are characterized by the least stability of temperature, by rapid changes from thaws to low temperatures. The effect of fluctuations of temperature has been proven by Heppert's laboratory experiments. Thus *Poa annua, Senecio vulgaris, Capsella bursa pastoris,* and others withstood with impunity long snowless freezes with temperature as low as 14° F. and some even as low as 5° F. After several brief thaws, however, they all perished at a temperature of 24.8° F. The expression "absolute monthly range" may serve only for general orientation, and has no direct bearing upon plant life, since sufficient time may intervene between the occurrence of the maximum and minimum to permit of a gradual change in temperature. For plant life the mean daily range, and the maximum and minimum of the individual daily ranges, therefore, are of greater moment than the absolute monthly range. The mean monthly ranges are also of importance. The mean annual range is more important than the mean periodic range. Particularly instructive is a comparison of the general mean annual range with the mean annual range of temperatures computed separately for winds of different directions.

TABLE 3.—*Temperature of the air by periods of rest and growth.*

Month.	Absolute monthly range.	Mean daily range.	Maximum of the mean daily range.	Minimum of the mean daily range.	Mean monthly range.		
					General.	With easterly winds.	With westerly winds.
Period of rest.	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
November	50.2	9.4	27.4	1.4	....	....	....
December	41.4	8.1	20.2	0.9	....	....	....
January	36.9	6.9	19.8	1.8	....	....	....
February	32.2	9.0	22.1	2.3	....	....	....
March	41.8	10.1	23.8	4.0	....	....	....
April	38.3	17.1	29.7	2.0	....	....	....
Range for the rest-period	58.1	10.1	29.7	0.9	20.9	23.7	16.2
Period of growth.							
May	34.9	16.9	27.9	3.2	....	....	....
June	31.0	16.0	24.8	3.2	....	....	....
July	32.8	14.8	26.1	3.6	....	....	....
August	36.0	14.6	25.2	2.7	....	....	....
September	41.6	12.6	25.4	2.5	....	....	....
October	36.9	14.4	23.2	5.2	....	....	....
Range for the growth-period	50.8	14.8	27.9	2.5	15.8	19.8	12.7
Range for the year	77.5	12.4	29.7	0.9	38.0	43.4	34.0

The method suggested here of grouping the temperature of the air will not show the actual amount of heat required for the development of the vegetation in a given locality. Its purpose is merely to furnish material for a more thorough comparison of climates from a biological and meteorological standpoint.

In order to determine the extent to which different plants actually utilize the heat, it is necessary to resort to another method. A number of attempts have been made to secure this information by computing temperature and other meteorological records for the period of growth of a few of the more important agricultural crops.

At first glance such a procedure seems very expedient, but it is doubtful if it can yield practical results. No matter whether an attempt is made to compute the average temperature for a given phase of plant development, or whether the positive temperatures are summed up for a period in the same way in which Bussengo and De Candolle have done it, the underlying idea is the same, namely, that the effect produced by heat upon plants is proportionate to the amount received during the period. In reality there is no such direct relation. On the contrary, for each phase of plant development there exists a definite optimum of temperature, moisture, and light at which the development goes on with the greatest vigor. When the temperature (or moisture, or light) deviates in one direction or the other from this optimum, the development slows down, and when temperature falls below a certain minimum or rises above a certain maximum it stops entirely. The warmer the climate, the more frequently the temperature exceeds the optimum at which the plant develops best and the more often the plant will receive a useless and sometimes harmful surplus of heat. Yet by summing up temperatures or by computing the average temperature for the period, this useless or often harmful excess of heat invariably increases the summation or the average temperature. For this reason, the farther south the greater must be the sum of useful temperature required by the same species to go through a given phase in its development. This clearly shows, it seems to me, that neither the summation of positive temperatures nor the average temperatures for any period can indicate the actual requirements of plants for heat; and most botanists since the time of Grisenbach have given up summation of temperatures.

Bussengo and De Candolle probably would not have suggested this method of summation if they had known about the existence of optimum temperatures for the development of each plant, as determined later by Sachs. There are also some other indications which confirm the fact that plants do not react to heat as simple engines. Thus, for instance, the dormant roots of the lily of the valley, or the dormant branches of cherry were found, when starting growth next spring at the same temperature, to require less time for their development the later their growth had been interrupted in the autum, notwithstanding the fact that in these dormant organs before the interruption of their growth no changes had taken place which could be detected macroscopically or microscopically. Furthermore, not only different species and varieties, but even different biological races of the same variety which morphologically do not differ one from another, require for their development very different amounts of heat. In such cases it would be necessary to compute separately the average temperatures for various periods of development, to sum up the temperatures not only for each species, but even for each of its races, which is a practical impossibility. All this tends to show how unreliable and of how little practical value to the biologist is the method of computing average temperatures, or the summing up of temperatures, for different species of plants separately.

Groups of days with a definite temperature.

The relation of plants to heat is expressed not in the absolute amount of heat required by them, but in a certain combination of time and heat. At its optimum of temperature each plant requires a definite number of days in order to complete a given phase of its development. Any deviation from the optimum in one or another direction will lengthen this period.

Gardeners have learned, in an empirical way, how to manipulate temperatures in hothouses for forcing plants to complete a certain phase of development within a given time. They do not resort to summation of temperatures, but distinguish groups of days with a given range of temperature. Each group of days may embrace temperatures of five consecutive degrees. Fluctuation of temperature within these five degrees is of little consequence. They watch carefully, however, to see that the temperatures during a definite number of days do not fall to the level of the temperature of the group of days preceding it, or rise to the temperature of the group of days that is to follow it. Instead of summation of temperatures, this method seems to me preferable. Groups of days with definite temperatures can be readily computed separately for individual species; also, the entire year may be divided into such groups, as shown in Table 4.

The division of the entire year into groups of days with different temperatures is not a new idea. Many botanists have adopted such a division. Thus, following the scheme suggested for climatology by the meteorologist Köppen, some botanists distinguish: *freezing days* with average temperatures of 32° F. or less, *cold days* with average temperatures up to 50°, *moderate days* with average temperatures up to 68°, *hot days* with average temperatures above 68°, and *hot days with moderate nights* when the minimum temperature is about 50°. Such grouping, however, is too large and schematic. The method used by the gardeners seems to me more practical, and with modifications can be adapted to meet such conditions as exist outside of a greenhouse.

The following simpler classification is here suggested:

1. *Freezing days*, with a daily average of 32° F. or less. These are further subdivided into:

(*a*) Freezing days without thawing.
(*b*) Freezing days with thawing.

2. *Cold days*, with an average daily temperature ranging from 32° to 40° F. This group should be further divided into:

(*a*) Days with frost.
(*b*) Days without frost.

3. *Cool days*, with an average daily temperature from 40.1° to 50° F. This group should be divided into:

(*a*) Days with frost.
(*b*) Days without frost.

Cool days with frost are more dangerous than cold days with frost and occur in localities where the mean daily range of temperature is great.

Days with frost are thus divided into three groups: (1) Freezing days with and without thawing, (2) Cold days with and without frost, (3) Cool days with frost. During the cool days of the spring plants prepare for the period of vegetation, when the germination of seed takes place and the buds of the hardier species open.

4. *Moderate days* with an average daily temperature from 50° to 59° F. These are days of moderate growth. For the four groups of days so far established (freezing days, cold days, cool days, and moderate days) it is desirable to note the temperature separately for the days the ground is covered with snow and for days without any snow cover.

5. *Warm days* with an average daily temperature from 59° to 72°. These are the days of most vigorous growth and the ripening of fruits in the temperate altitudes and latitudes. For most of the plants of the Temperate Zone this is the most important group of days.

6. *Hot days* with an average daily temperature above 72°. In localities where hot days occur comparatively

often, especially when there is a distinct hot period, the hot days must be further subdivided into three groups, not so much, however, on the basis of temperature as on the basis of their humidity:

(*a*) Dry hot days, which act depressingly upon vegetation.

(*b*) Moderately humid hot days, which expedite the ripening of southern fruits.

(*c*) Humid hot days, which produce a tropical growth of plants of the humid subtropical region.

The total sum of days of all six groups (freezing, cold, cool, moderate, warm, and hot) must make 365 or 366.

TABLE 4.—*Days having specific air temperatures, by periods of rest and growth.*

Month.	Number of freezing days.				Number of cold days.				Number of cool days.				Number of moderate days.		Warm days.	Hot days.	Hot days with moderate nights.
	Without thaw.		With thaw.		With frost.		Without frost.		With frost.		Without frost.		With snow on the ground.	Without snow.			
	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.					
Period of rest.																	
November	1		2	1	1	1		8				16					
December	4	3		4	4	11	2	3									
January	28		3														
February	4		2		10				3		4						
March	2		6		12		9				2						
April	2		1		5	1	4	2	1	1	1	10		2			
For rest-period	41	3	14	5	32	13	15	13	4	1	7	26		2			
Period of growth.																	
May								2				12		17			
June												2		15	13		21
July														2	29		31
August														7	23	1	31
September												4		11	15		23
October												21		7	3		4
For growth-period								2				39		59	83	1	110
For year	41	3	14	5	32	13	15	15	4	1	7	65		61	83	1	110

The temperature of the soil.

The records of the temperature of the air are characteristic of the environment that surrounds the superterranean part of the plant. The other parts of the plant (the roots) develop in the ground under different temperature conditions. Observations, therefore, on the temperature of the soil are absolutely essential for the proper understanding of plant life. This phase of observation is specially appropriate to agricultural and forest experiment stations.

Topographic conditions affect the temperature of the soil to a more marked degree than they do the temperature of the air. Moreover, the temperature of the lower layers of the air is regulated by the temperature of the soil more than by the direct rays of the sun. The topography of the locality, therefore, must always be taken into consideration in installing soil thermometers. It would be advisable to install a complete set (at a depth of $1\frac{1}{2}$, 12, and 24 inches) near the station itself and in addition, for comparison, two or three incomplete sets (at a depth of $1\frac{1}{2}$ inches and 24 inches) under different topographical conditions.[1] Since the temperature of the soil depends to a large extent upon its physical structure, it is essential, in order to obtain comparable results, to take the physical qualities into account. Therefore, in localities where the physical quality varies within short distances, it is essential to have an additional set of thermometers to bring out the effect of this difference. It may be also advisable to have a set of minimum and maximum thermometers located horizontally on the surface of the soil, although it is hard to determine just what such thermometers do indicate—the temperature of the upper layer of the soil or of the lower layer of the air.

The effect of the temperature of the soil upon the development of plants is unquestionable. The period of rest of the roots is, however, less marked than that of the superterranean parts and in many of the more southerly altitudes is entirely absent. The period of rest for the roots is less stable than the period of rest for the superterranean parts and therefore is more easily affected by artificial means. For this reason, the grouping of temperature records of the soil on the basis of cold, moderate, and hot periods determined on the basis of the average monthly temperature of the air, is not entirely suitable. The lack of observations and investigations along this line, however, does not yet permit of suggesting any other grouping at present; and it may be just as well, at least for the present, to classify the records of temperature of the soil by the periods adopted for plants in general. It may be mentioned here that roots stand sudden fluctuations of temperature even to a less degree than the superterranean parts of plants.

OTHER METEOROLOGICAL DATA.

I have dwelt at length upon temperature because I believe that the system of observations I have outlined in its case should be followed in computing all other meteorological data. The discussion of these latter, therefore, will be brief.

Humidity of the air.

In localities with a dry climate, especially where there is a distinct hot period, observations upon the humidity of the air are essential. While the absolute humidity is

[1] Probably in some instances measurements of soil temperature at a larger number of depths may be desirable. It is believed, however, that for all purposes three depths should be sufficient. Intermediate depths can be computed very accurately by interpolation with curves on which the three points are established.

of no direct consequence to plants, its importance being purely meteorological, the relative humidity affects them directly, since it so largely determines the amount of transpiration. The monthly mean relative humidity and its minimum, and particularly the average relative humidity with its minimum during periods of different wind direction, are things important to know. In localities with a humid climate and without a distinct hot period, where fogs are frequent, observations upon the latter should, of course, give all the information as to humidity of the air necessary for the purposes of botanical geography.[2]

Precipitation.

The important part which precipitation, especially total precipitation, plays in plant life, needs no discussion. The maximum precipitation for any day during the month and the number of days of precipitation are also important. Since among the latter, however, are included days with only traces of precipitation, the resulting data does not give an idea of the intensity of the precipitation or its frequency. For this reason it will be well to compute the number of days with considerable precipitation in per cent of the total number of days of observation in general, as well as specifically, for winds of different direction.

Snow cover.

Snow cover, of course, also has an important effect upon plant activity. Both the number of days with snow on the ground and the depth of the cover should be recorded. Since the depth of the snow varies with the topography, its depth should be measured at different places. In the valley the snow stakes should be placed, if practical, in an open field and in a wood lot; in the mountains on a level place and on two moderate slopes of the prevailing directions. For each month the average depth of the snow cover should represent only those days when snow was actually on the ground. In order to determine the effect of local topographic conditions, it would be well to note the averages separately for each snow stake. Data on the maximum and minimum of snow cover for each month are also essential, and it is very useful to have the depth of the snow separately for every 10 days (decade). Such detailed information concerning the snow cover is especially instructive at the time of its appearance and disappearance. Since it comes and goes in different years and in different localities at different times, however, this average depth should be given for all 36 decades.

Soil moisture.

In dry regions it is necessary for purposes of botanical geography to have a more detailed knowledge of the humidity of the soil than would ordinarily be indicated by the amount of rainfall and snowfall. In such places periodic and systematic determinations of soil humidity giving due consideration to local topographic and soil conditions are important. Unfortunately, such determinations are not only time consuming, but require a great deal of judgment in the selection of soil samples. The amount of moisture in the soil depends upon the latter's physical properties, its method of cultivation, and so on, and can not be determined accurately at the ordinary weather stations. Therefore it would be of great advantage to students of plant life if such determinations could be made at agricultural and forest experiment stations.[3]

[2] The adoption by all weather stations and observers of a standard evaporometer would, in a large measure, solve the question of humidity and wind-movement records and would furnish data directly usable by the plant bi ologists.

Sunshine.

Light is another important factor in the development of plants. The amount available for plants in a given locality depends upon cloudiness and geographic latitude. For this reason, the average monthly cloudiness, the average cloudiness for winds of different directions, and the number of clear, semicloudy, and cloudy days should be computed. Some simple sunshine record, especially for winds of different directions, is also necessary. The occurrence of days with sunshine should be given in per cent of the total number of observations.

Barometric pressure.

Air pressure has no direct bearing upon plant life, except that its observation often makes it possible to forecast changes of importance to agriculture.

CONCLUSION.

In conclusion, I wish to reiterate what I said at the beginning, namely, that, with the exception of the records of soil humidity and soil temperature, the system of meteorological observations I have outlined can be carried out with the data which are regularly obtained by our weather stations. The change from present practice to the system I have described will entail, therefore, merely a different use of present data rather than a radical change in the plan of collection. The aid to botanical geography which such a change would give would far more than compensate, I think, for any inconvenience or added effort that it might bring about.

TASKS AND PROBLEMS FOR METEOROLOGICAL EXPLORATIONS IN THE ANTARCTIC.

By Prof. Dr. WILHELM MEINARDUS, Münster, Westphalia.

[Translated by Cleveland Abbe, jr., from Geographische Zeitschrift, Leipzig, 1914, 20. Jhrg., 1. Hft, p. 18-34.]

No other region on the earth has witnessed during the past decade, such advances in our knowledge of its meteorological conditions as has that within the higher southern latitudes. As Hann was closing the second edition of his Handbook of Climatology in 1897 he was practically limited in material for the climate of the Antarctic Zone, to that collected in its seas 50 to 60 years previously by Sir James Ross. There was no

[3] Here again the adoption of a standard apparatus seems the only means of obtaining desirable data for large areas and for different regions. The great difference in soils in different localities and the great difficulty in any one locality of obtaining consecutive samples of soil which are physically alike, makes it necessary that any apparatus designed for consistent soil-moisture determinations shall involve the plan of always measuring the same body of soil. The electrical resistance apparatus is good in this respect, but, unfortunately, is not always reliable from a mechanical standpoint. A comparatively simple piece of equipment has been suggested by C. G. Bates of the Fremont Forest experiment station. This is a porous cup which would contain the sample of soil whose moisture was to be determined periodically. This porous cup would fit closely inside a second similar cup, which would, in turn, be located at the bottom of a brass tube at any desired depth below the surface of the ground. To the soil cup would be attached a cord or rod which would extend up through the brass tube. At the top of the tube would be a firmly built platform, on which could be placed a sufficiently delicate balance for weighing the soil cup. When weighing was desired the cup would be raised sufficiently to clear the exterior cup attached to the beam of the balance and then replaced. The contents of the cup might be a sample of the local soil, a standard sand or soil of certain physical and mechanical properties, or a standard salt with a slight avidity for water. Under either plan the moisture of the contents (by absorption or expulsion through the porous walls) would always bear a certain relation to the moisture of the surrounding soil.

information available for the Antarctic mainland, whose areal extent is one and a half times that of Europe. Indeed, but 15 years ago Antarctica had not yet one single meteorological station, so that Hann closed his work with the words: "Eine, oder noch besser mehrere Überwinterungen in hohen südlichen Breiten würden einige der wichtigsten und interessantesten Probleme der wissenschaftlichen Klimatologie zu lösen imstande sein. Die Kenntnis der Wintertemperatur im Polargebiet einer Wasserhemisphäre ist gegenwärtig das dringendste Erfordernis unserer Wissenschaft."

The desire of our greatest climatologist that there might be one or more winter-long expeditions to the Antarctic, there voiced, was soon to be fulfilled. The first wintering was in 1898–99 in the seas west of Graham Land, by the Belgian expedition under De Gerlache in the *Belgica*. It was not granted this expedition to establish a land station; caught in the floes the ship was compelled to drift along an unknown and unseen stretch of the Antarctic coast. Borchgrevink's expedition to Ross Sea was the first to establish and maintain a land station. It was located at Cape Adare for almost a year in 1899–1900. These two expeditions were the advance guard of a new epoch in Antarctic exploration which began with the new century. It is still fresh in the memory and its latest victories, the extension of our horizon to the South Pole itself by Amundsen and Scott, still thrill us. I may then pass over the various stages of this latest activity in exploration. Germans, French, English, Scotch, Norwegians, Swedes, Argentinians, Australians, all have had a part so that this field of exploration is more truly international in character than any other on the globe. Here the fame of success beckons not merely to the ambitious explorer, but more alluringly to the investigator who would sink himself in study of the peculiar nature of a lonely, sea-surrounded icy continent never yet even brushed by any form of human culture.

It is my purpose to communicate some of the meteorological results[1] which may be based upon the observational material collected by the Antarctic expeditions of the past decennium, as well as to review the still unsolved problems which must spur us onward to further exploration in Antarctica.

CHARACTER OF PREVIOUS METEOROLOGICAL OBSERVATIONS.

We may begin by considering the character of previous collections of meteorological observations in our field and their evaluation. (See the map, fig. 1.)

Observations have been made at mainland stations, on sled journeys, on drifting floes, and recently also by means of kites and balloons.

Fixed land stations.—In studying the atmosphere, stations at fixed points are of the most value, because the external conditions of the surroundings remain the same. Such observations, when continued through one or more years, can be used to determine seasonal contrasts and to ascertain averages that apply to the surroundings of the station. Such stations have the further advantage that they can be revisited by other expeditions, so that one may secure comparable data for various years.

So far eight localities within the true south polar region have been occupied as meteorological stations of some duration and one of them, Adélie Land, is still maintained. These stations were located as shown in Table 1 and the map, figure 1.

TABLE 1.—*Meteorological stations in Antarctica occupied for one or more years.*

Station.	Nationality.	Lat.	Long.	Periods.
West Antarctica.				
Laurie Island	Scotch / Argentine	60° 44′ S.	44° 39′ W.	1903–1914 (?).
Snow Hill	Swiss	64° 22′ S.	57° 00′ W.	1902–3.
Port Charcot	French	65° 04′ S.	63° 42′ W.	1904–5.
Petermann Island	do	65° 10′ S.	63° 54′ W.	1909.
East Antarctica.				
Cape Adare	Norwegian	71° 18′ S.	170° 09′ E.	1899–1900.
Gauss Station	German	66° 02′ S.	89° 38′ E.	1902–3.
MacMurdo Sound	English	77° 45′ S.	160° 30′ E.	1902–1904, 1908–9, 1911–1913.
Framheim	Norwegian	78° 38′ S.	164° 30′ W.	1912–13.
Adélie Land	Australian	66° 30′ S.	140° 00′ E.	1912–1914 (?).

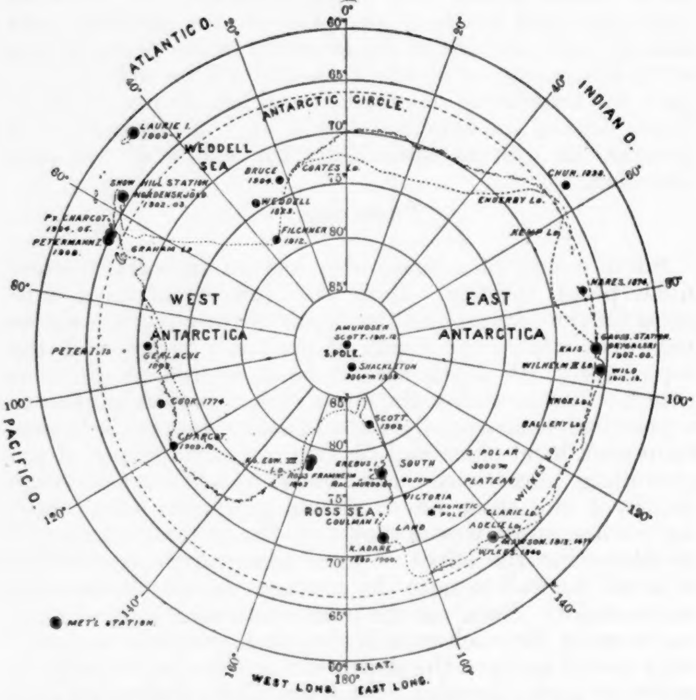

FIG. 1.—Location of meteorological stations within the south polar regions.

Some of the stations listed have had branch stations in their vicinities for longer or shorter periods, e. g., on the Gaussberg, on Mount Erebus, etc.

Thus it appears that so far the fringe only of the Antarctic continent has been occupied by fixed stations, of which the southernmost is Amundsen's "Framheim" in lat. 78° 38′ S., or about 1,300 km. from the South Pole; Spitzbergen has a corresponding location on the Northern Hemisphere.

Sled journeys.—Another kind of material is secured on the polar sled journeys, which usually have one of these fixed stations as their starting point. In the nature of things these observations can be but scattered samples of the atmospheric conditions along their routes. Because of the almost continuous change of place the individual observations can not be summarized and given general application. In general, all the elements observed vary with each locality, so that in utilizing meteorological observations made on sled journeys one must always bear in mind that the weather then encountered may depart more or less widely from the average conditions or climate

[1] See also Hann's exposition in his Handbuch d. Klimatologie, 3d ed. Stuttgart, 1911, v. 3, p. 677–699.—W. M.

of the region. This fact has not always been considered, and the resulting hasty conclusions may readily be undermined by later observations. Furthermore, sled journeys are usually undertaken during the polar daylight, so their observational material is applicable only to a certain season of the year. However, sled journeys can furnish information of general value concerning the climate of the regions traversed by recording the depth of the snow and the ice covers, the orientation of the snow dunes, phenomena of melting, and such features. In this way they are always very important aids to our knowledge in case other means fail.

Sled journeys of major significance have been limited to the eastern portion of Antarctica. The trips in Victoria Land made by the English expeditions seeking the magnetic South Pole are specially noteworthy We would not omit to mention the poleward trips associated with the names of Scott, Shackleton, and Amundsen.

Floe-drift journeys.—A third class of observations result from expeditions compelled to drift in the ice floes. The usefulness of such material is intermediate between that of the fixed stations and that from sled journeys. The floe-drift and the fixed station agree in that the surroundings do not materially change during the period of occupation, for the observation is always at the ship and the surroundings are always snow and ice. On the other hand the gradual shifting as the floe moves is similar to that of the changing sledding camps, although the former is very slow, while in the latter case rapid changes are specially emphasized. Accordingly the floe-drift observations acquire more or less significance as the duration and direction of the drift journey varies.

The essentially floe-drift expeditions to the Antarctic include the *Belgica* expedition west of Graham Land in 1898-99, the *Scotia* expedition of 1903-1904, and the German Antarctic expedition of 1912 in Weddell Sea. Besides these a large number of other expeditions have been compelled to drift sometimes for months, as was the lot of the German South Polar Expedition from the beginning of February to the beginning of April, 1903, after it had left its winter quarters.

Kite and balloon observations.—Finally come the endeavors to learn the nature of the higher atmospheric strata by means of kites and balloons. Here also the results are mostly in the nature of isolated samples of the meteorologic conditions; and again it must be borne in mind that the observations are determined by the momentary weather conditions, so that they do not suffice for general averages unless they can be repeated daily at the same locality. Great care must be used in basing general conclusions upon such material. However, this in no way detracts from these upper-air observations since they are of the greatest significance to studies of the momentary conditions and of weather sequence.

Certainly one of the greatest triumphs of the German South Pole Expedition was Dr. Barkow's [2] successful carrying out of 255 ascensions on 209 days during the floe-drift journey in Weddell Sea. A preliminary computation indicates that the highest balloon sounding reached an altitude of 17,200 meters [56,430 feet, or 10.7 miles]. These series of flights furnish the first noteworthy data bearing on the upper-air conditions over the Antarctic regions, and we may well look forward expectantly to the general conclusions which this first pioneer work shall warrant. Under other circumstances one must rely upon cloud observations for information bearing upon upper-air conditions, and numerous contributions of this kind have already been made.

[2] *Barkow, E.* Vorläufiger Bericht über die meteorologischen Beobachtungen auf der Deutschen Antarktischen Expedition. Veröffentl. Preuss. meteorol. Institut. Berlin, 1913.

NEEDS IN FUTURE EXPLORATION.

In general, it is clear from the foregoing that future expeditions to the Antarctic will best further the study of its climatology if they establish long-lived fixed stations which shall be located as far inland as possible. It seems that the establishment of subsidiary stations is also very useful, since they aid in determining the extent of local conditions. Of course such expeditions will also arrange for simultaneous kite and balloon flights. We may well hope that the modern and future development of aeronautics will also contribute to the exploration of the South Polar regions.

METEOROLOGICAL CONDITIONS AND PROBLEMS OF ANTARCTICA.

Previous observations on the atmospheric conditions of the Antarctic continent have revealed many unexpected problems. Foremost among these is the element "Temperature" which directly or indirectly sets its stamp upon the country.

Summer temperature.

The low summer temperature is the most important characteristic of the South Polar temperature distribution. The average temperature of the warmest month, December or January, is below 0° C. almost everywhere along the borders of the Antarctic mainland. The only exception to this is the west coast of Graham Land, where the French expedition found a mean January temperature of 1° C. in latitude 65° S.; and this is offset by a mean January temperature of only −0.9° C., found by the Swedish expedition on the east coast of the same land in latitude 64° 30′ S. If one computes the average January temperatures for the latitude circles it appears that the isotherm for 0° C. almost coincides with the Antarctic Circle (lat. 66° 30′ S.). The region bound by this curve has an areal extent of 21,000,000 square kilometers, more than double the extent of Europe [or of Australia, and about half that of the Americas]. In spite of its favorable summer insolation [perihelion summer], this extensive region stands under the sign of Jack Frost.

The North Polar regions have far more favorable conditions. Mohn's discussion of the observations by Nansen's expedition in the *Fram* indicates a July temperature below 0° C. prevailing over a limited area (800,000 square kilometers), within the latitude of 85° N. Thus in the warmest month the isotherm of 0° lies but 450 kilometers from the pole in the north, while in the south it has an average distance of 2,600 kilometers from the corresponding point.

But the summer temperatures of the southern polar regions are not merely close to freezing; the farther poleward one goes the farther sinks the summer temperature below 0° C., in spite of the more favorable insolation conditions. So that Amundsen found the average temperature of the warmest month (December) at Framheim (lat. 78° 38′ S., alt. close to sea level) to be but −6.2°. This is a fact difficult of explanation, since the insolation at this high southern latitude continues uninterruptedly day and night through the summer months except as it may be decreased by the rather slight cloudiness. The sled journeys toward the South Pole also show altogether unusual low temperatures for the summer season in which they were made. A midsummer temperature of −50° C. (−58° F.) is not to be readily explained even though the district about the South Pole itself does lie at an altitude of over 3,000 meters [i. e., over 9,840 feet].

One of the principal problems for future expeditions will be to find the explanation of this low summer tem-

perature at high southern latitudes. It may be expected that future upper-air investigations will aid in the solution.

Winter temperature.

Another heretofore unexplained phenomenon is the uniformity of the winter temperature during April to September. The feature is most pronounced in East Antarctica at the English station on MacMurdo Sound. There the monthly temperatures remain between 24° and 27° C. from April to September. The annual temperature curve seems to be flattened, quite in contrast to its course in the Northern Hemisphere where the temperature sinks rapidly until midwinter when it immediately begins to rise again. Why is there no pronounced Antarctic winter month whose low temperatures distinguish it sharply from its neighboring adjacent months?

Local temperature contrasts.

The local differences in temperature distribution over the margin of Antarctica will not be discussed here. It must suffice to say that the east and west sides of Graham Land show important differences, the west side being warmer than the east side. This feature is primarily referable to the different wind conditions, and it may well be compared with the differences prevailing between the west and east coasts of Greenland.

There is a surprising and unexplained difference between the observations at Framheim (Amundsen) and at MacMurdo Sound (English). Although both localities are in almost the same latitude, are at sea level, and similarly located at the edge of the Ice Barrier, yet there is a difference of not less than 7.5° C. between the two annual means, Framheim being colder than MacMurdo Sound. Further, Framheim shows the lowest mean annual temperature (−25.2° C., −13.4° F., in lat. 78° 38′ S.) so far observed anywhere on the globe. The lowest average temperature observed during the *Fram's* drift in the Arctic Ocean was −20.5° C. (−4.9° F.) for 1895 and an average latitude of 85° N. Some years ago the author computed the average annual temperature for the South Pole and found −25° C., a result which will probably be regarded as somewhat too high.

Does the cold pole of the Southern Hemisphere coincide with the south geographic pole? This problem awaits solution. Previous observations make it probable that the cold pole is located somewhat eccentrically, being shoved over toward the Indian Ocean, for the antarctic shores of the South Atlantic and South Indian Oceans are somewhat colder than those of the South Pacific.

Pressure and winds.

The more recent investigations show the sea-level pressures and winds of West Antarctica are about what theory would predict. Wind conditions indicate that a trough or furrow of low pressure surrounds the south polar regions in latitudes 60° to 70° S., and an increasing pressure from those latitudes poleward. (See fig. 2.) The low-pressure trough or furrow, appropriately designated the subantarctic circumpolar barometric trough or furrow, is thus seen to act as an important wind divide.

Formerly it was believed that the east winds south of the trough were blowing from the high-pressure area supposed to cover the antarctic lands. These east winds were supposed to be of antarctic origin and to have the dry, cold character of winter land winds such as might blow from an area of continental high pressure. Observations in these regions have not supported this view. On the contrary the east winds met with in the marginal region of the westerly winds are not dry and cold but moist, warm, and snow-producing. Drygalski's German South Polar Expedition established this point most clearly. As the *Gauss* sailed southward from Kerguelen in February, 1902, she was for a while in the zone of westerly winds, but after crossing latitude 64° S. entered the region of easterly winds where she remained for over a year. During this time the prevailing wind was easterly and whenever these east winds showed marked increase in force the weather became warm and moist with copious snowfall. To be sure the higher temperature of the east winds might be explained by assuming they are of southern origin and a föhn-like character; their higher humidity contradicted this view. The heavy precipitation characterizing these east winds is yet more discordant with the föhn theory.

If these easterly winds of the *Gauss* station are regarded as cyclonic in nature their warm, moist character is readily and adequately explained. In this case their origin must lie to the north, that is in the region of the southern Indian Ocean. This view also harmonizes with the observed subantarctic trough of low pressure which serves as the path of the depressions that march from west to east about the South Polar regions.

Of course in the barometric depressions of the Southern Hemisphere the air circulation is spirally clockwise. (See fig. 3.) Accordingly the east winds on the south side of these depressions must have a northern origin. They are coming from warmer latitudes and from the ocean, and their higher temperature and humidity is a natural consequence. The winter station of the *Gauss* was particularly favorable for the clear development of these features. No mountains, peninsulas, or other topographic features could disturb the air currents. The even coast of Kaiser Wilhelm II Land stretches from west to east and the *Gauss* station was located 90 km. north of the coast.

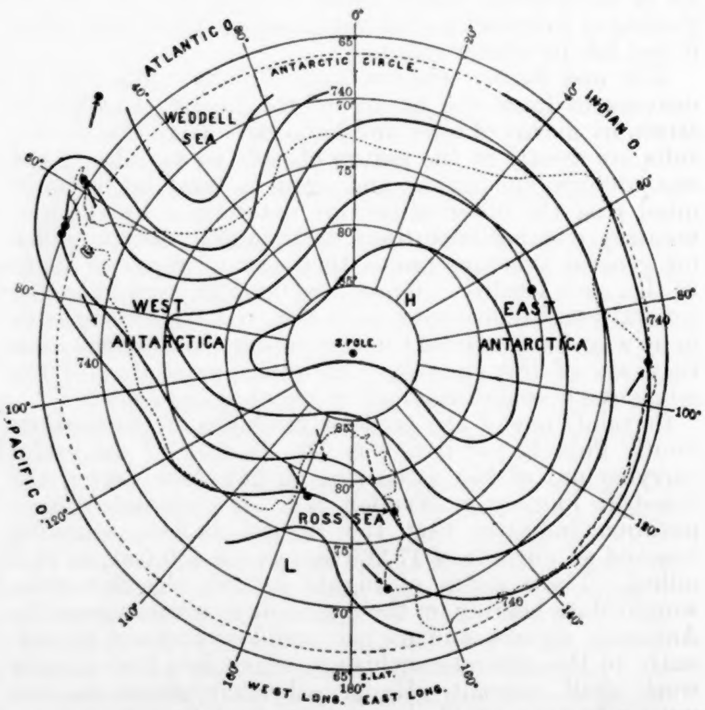

FIG. 2.—Sketch of the course of the isobars at sea level within the south polar regions. The isobars are intentionally unnumbered except the curve for 740 mm., whose position can be plotted with some certainty by aid of past observations. The drawing is planned to present only the *probable form* of the isobars, considering the observed sea-level winds. H, high pressure; L, low pressure; arrows, average wind direction.

Most of the other Antarctic stations have had similar experiences with the east winds. Thus the warmest winds were from the northeast and north at the Swedish station on the east side of Graham Land, and at the French stations on the west side of the same. The *Scotia* had cyclonal northeast winds at the east side of Weddell Sea. In and about Ross Sea the conditions are more complicated. Here the mountains of Victoria Land, modify the direction and the character of the air currents which can not be so simply described. It must be assumed that the barometric trough which forms the divide between the easterly and the westerly winds, bends southward in the region of Ross Sea or that there is here a tendency to develop an independent pressure minimum. It then becomes clear (see fig. 2) why the southeast winds were the warmer at the English stations in the southern portion of Ross Sea.

The distribution of pressure and winds over Weddell Sea show similar modifications. Mecking and Mossmann find this region dominated by low pressure especially during the winter, so that southwest winds prevail along the west side and northeast winds prevail along the east side. The floe-drift observations on the *Deutschland* in 1912 confirmed these assumptions.

The modern explorations have thus necessitated some modifications of the simple scheme of pressure and wind distribution to bring it into accord with the continental outline of Antarctica. The most important fact emerging from these observations is that the easterly winds of the continental margin must be regarded as members of the circulation about centers of low pressure passing north of Antarctica. The east winds to the south of the sub-Antarctic circumpolar barometric trough are the necessary corollaries of the west winds to the north. A comparison of the weather observed at Kerguelen and at *Gauss* station shows this.

The international meteorological coöperation of 1901–1904, originated by the German Antarctic expedition, was able to follow the course of the weather in high southern latitudes much more accurately than the expedition could have done alone. Mecking and Meinardus have drawn up synoptic weather maps for the Southern Hemisphere south of latitude 30°, whereon one may trace the paths of the highs and lows across the seas surrounding Antarctica. The study has not yet been completed, but it is already possible to state that these charts confirm the view which regards the marginal east winds of Antarctica as elements of cyclonal systems.

The mechanics of these depressions appear to be much more complicated than we have heretofore been ready to assume. It had been thought that in the broad zone of water uniting the oceans on the south the development and movement of the pressure system would show simpler features than in the northern zone of our latitudes, where continents and seas alternate. But in the south, also, the relations are complex; lows and highs undergo varying modifications, and their movements do not show that uniformity that the expedition of 1901 expected to find when it sailed for the south.

A question still unanswered is as to the great constancy of the east winds. At the winter quarters of the *Gauss* these winds blew with a constancy almost equaling that of the trades; rarely were they interrupted by calms or by westerly winds. There is undoubtedly some relation between the simple character of the coast line and this constancy of the east winds, but their dependence upon the advancing depressions on the north leads us to expect a lower degree of constancy in these winds.

We also need further explanation of the unusual frequency of the extremely stormy, cold southwest wind recorded at the Snow Hill station. As was stated above, this wind indicates a region of low pressure over Weddell Sea, but it is striking that the wind is dry and cold and therefore can not be considered as of truly cyclonal character. We shall return to the consideration of this wind.

Precipitation.

Certainly the chief characteristic of the Antarctic precipitation is that it almost always takes the form of snow. Rainfalls belong to the greatest rarities. This explains why so little has been known as to the amount of precipitation for, as is well known, there are great difficulties in the way of the measurement of snowfall and particularly in the polar regions which are covered with loose snow.

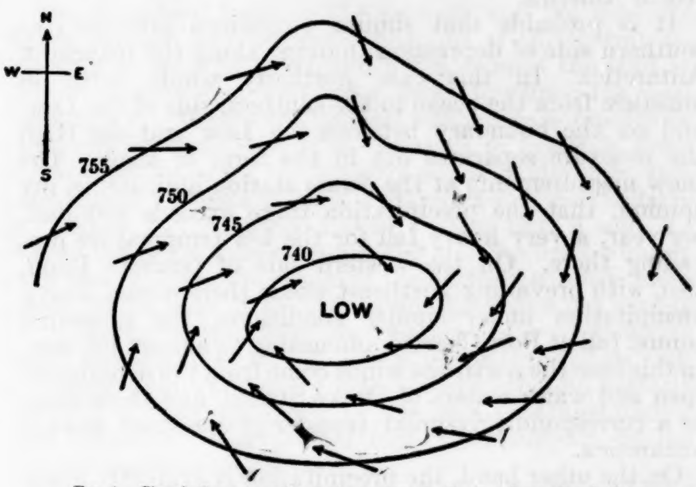

FIG. 3.—Circulation at sea level of a cyclone in the Southern Hemisphere.

Previously fallen snow is whirled up by the wind, and even during fine, dry weather drifting snow can fill the gages with falls that have already been measured. Even when actual new snow is falling it is blown from the gage and but a small part is measured. There are, indeed, devices for reducing such losses at the gage but they are not adequate to remove the source of error. In general it is safer to use staff gages set up at well-selected points so that uniform records may be secured for driftings of various intensities. The readings of such staff gages certainly yield more reliable results than those from the simple snow measurer, which is no other than a rain gage.

For these reasons the previous measurements in the Antarctic are hardly sufficient to give an accurate idea of its precipitation. Therefore it may be stated that one of the most urgent needs is a device which is adapted to securing records, even during an Antarctic snowstorm, that will permit a somewhat reliable estimate of the precipitation.

The available measurements will scarcely bear discussing; however, the following may be mentioned: When the east winds on the margins of Antarctica have a cyclonal character—i. e., are bringing moisture from northern latitudes—then it is very probable that they will bring specially heavy precipitation. Here we may point the analogous expectation in the North Temperate Zone that east winds on the poleward side of barometric depressions will bring unusually heavy precipitation. In Germany the heaviest snowfalls usually occur with northeast and east winds accompanying a Low over the Mediterranean to the south and a High over Scandinavia or

northwestern Europe. The process is as follows: On the east side of a depression the southerly winds bring moisture northward from the warm Mediterranean region and transfer it to the north side of the depression. Here, at the boundary between the cyclonal and anticyclonal areas, cooling causes precipitation which generally takes the form of snow. Now does the southerly depression move in general toward western Russia following storm path *Vb* [*see* Bebber, Lehrbuch der Meteorologie, *or* Milham, Meteorology, p. 301, fig. 124, *or* Bartholomew's Physical Atlas, v. 3, pl. 28], then there develops a belt of heavy precipitation parallel with the direction of the storm's path. The great snowfalls of March 15–17, 1894, over northeastern Germany and of March 9–12, 1901, associated with the extensive dust fall over northwestern Germany, are proofs of this process. It no doubt occurs also on the east coasts of Greenland and of North America.

It is probable that similar conditions arise on the southern side of depressions moving along the margin of Antarctica. In this case northerly winds bring in moisture from the ocean to the southern side of the Low, and on the boundary between the Low and the High the moisture separates out in the form of snow. The snow measurements at the *Gauss* station indicate, in my opinion, that the precipitation there exceeds 800 mm. per year, a very heavy fall for the low temperature prevailing there. On the western side of Graham Land, also, with prevailing northeast winds there occurs heavy precipitation under similar conditions, the measured annual fall at Port Charcot amounting to almost 400 mm. In this case the northeast winds come from the perennially open and warm waters of Drake Straits, and there must be a correspondingly great transfer of moisture toward Antarctica.

On the other hand, the precipitation is evidently much smaller in Weddell Sea and its western boundary. It is true that the observations at Snow Hill station are not usable, for the reasons already stated; nevertheless the precipitation can not be very large for prevailing southwest winds were generally dry in spite of the frequent schneetreiben which accompany them. The *Deutschland* also found very light precipitation during its floe-drift in Weddell Sea, only 98 mm. in amount. This measurement was by means of a rain gage, and though it may be quite inaccurate still, as Barkow says, this figure gives some reason for believing that the district is one of small precipitation.

On the whole, then I would regard it as very probable that those portions of the margin of Antarctica which are fanned by cyclonal easterly winds are regions of heavy precipitation. On the other hand those portions which, like western Weddell Sea and Ross Sea, are exposed to southerly winds are regions of light precipitation. Further observations are needed before more detailed conclusions may be drawn. Heretofore we have had but a general knowledge of the annual period of the precipitation, the observations indicating that the summer precipitation is heavier than that of winter.

Source of the inland ice.

Such investigations into the distribution of the Antarctic precipitation are, of course, of the greatest importance in one of the cardinal problems of the Antarctic: What are the meteorological conditions which supply and maintain Antarctica's continental ice sheet, the "Inland Ice"? That cover of ice and snow forms the most prominent feature of Antarctica, and it exerts the most far-reaching influence upon the climatological phenomena of all its surroundings. I have also studied the problem of the source of supply for the inland ice when working up the results of the German South Polar Expedition. Permit me to briefly present my views thereon.

It is a well-established fact that there is a steady flow of ice from the unknown interior of Antarctica. This ice sheet overflows the margin of Antarctica and presents an almost unbroken line where it surrenders to the sea in the form of icebergs. The origin of this ice can not lie along the continental margin only, it must also be located farther poleward for there can be no doubt that the interior mainland also lies snow buried as does its margin. Sled journeys into the interior and to the Pole prove that even in these central portions of the Antarctic mainland the determining elements of the landscape are snow and ice; nowhere appeared extensive snow-free areas.

Now if the interior of Antarctica is covered with snow and ice and there is a discharge of the same to the marginal oceans, it follows that over Antarctica as a whole the precipitation exceeds the evaporation. Marginal ice discharge could occur only in such a region. It further follows that the excess of precipitation over evaporation must be furnished by air currents moving toward the interior of Antarctica. The hydro-economics of Antarctica must be somewhat as follows: The marginally discharging ice is exporting water from the south polar regions; this water loss must be compensated by an excess of precipitation over evaporation; and the excess precipitation must be made possible by a corresponding supply of water vapor carried by winds into the interior.

If the water imported annually be designated by D_e, the exported water vapor by D_a, the precipitation by N, the Antarctic evaporation by V, and the exported ice by E, then under constant climatic conditions the annual state of affairs must be expressed by the equation:

$$D_e - D_a = N - V = E.$$

How can this equation be satisfied? This question can only be answered by considering the air currents and the distribution of pressure at levels higher than the earth's surface.

Antarctic pressures.

The general view is that the whole south polar region is dominated by a region of high pressure. This view is based upon the existence of easterly winds on the margin of Antarctica and the observed southward increase of pressure. We have already seen that the margin of Antarctica is not under anticyclonal but cyclonal pressure conditions. If there is an Antarctic anticyclone it can exist only in the inner portion of Antarctica (see fig. 2); and its existence there is a difficulty in the way of explaining the necessarily assumed interior snow cover. For air flows toward an anticyclone in its upper layers, then descends as relatively dry air, and below flows outward in all directions. Under such circumstances, unfortunately for the theory, precipitation cannot form in sufficient quantities to outbalance the evaporation as expressed in the above equation. On the other hand, evaporation is greater than precipitation in anticyclonal areas; the air descending from greater heights is dynamically heated, becomes relatively very dry, and as it flows outward takes up moisture from the earth's surface and removes it from the region of the anticyclone. In our case this known mechanism of the anticyclone would neces-

sarily cause a drying-out and removal of snow cover in the interior of the south polar regions.

This consideration induces me to revise the theory of an Antarctic anticyclone. A certain line of reasoning, which I shall not repeat here, shows me that the Antarctic continent must have a very high mean elevation, as much as $2{,}000 \pm 200$ m. above sea level. Herein lies the key to the phenomenon of Antarctica as a possible and even actual source of supply of the inland ice. For now one may draw the following conclusions: The Antarctic anticyclone, so much discussed in the past, is a pressure distribution peculiar to the lower atmospheric strata only, appearing with distinctness only in the sea-level pressure distribution. On the other hand the low Antarctic temperature must produce such a rapid vertical decrease in pressure that above a certain level the Antarctic pressure must be lower and not higher than that of surrounding regions. Thus the sea-level anticyclone must be overlain by a cyclone, the so-called "polar whirl" in the general circulation of the globe. (See the characteristic isobars at 4,000 m. in fig. 4.)

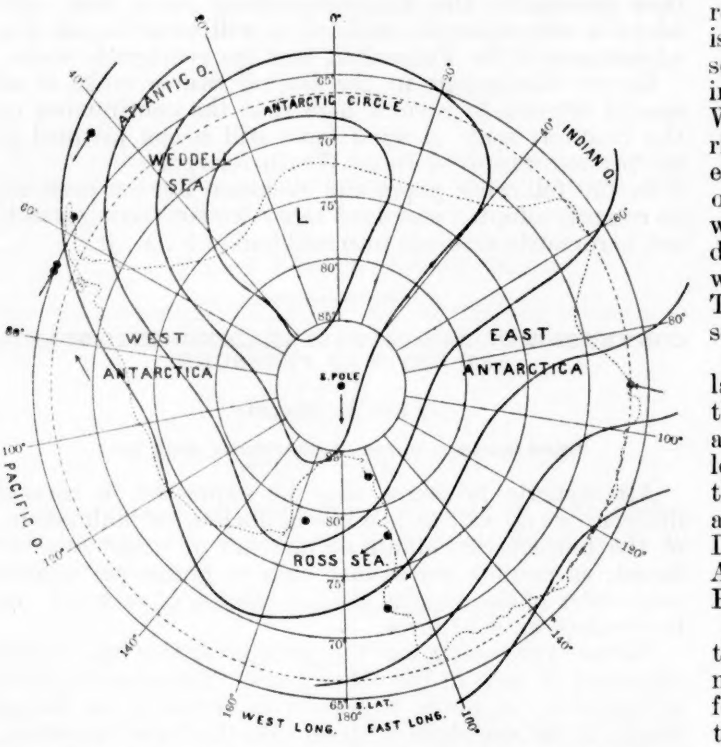

FIG. 4.—Sketch of the isobars at the 4,000-m. level within the south polar region. Arrows show average direction of the upper clouds and the prevailing winds on the plateau.

By making certain assumptions regarding the distribution of temperature and pressure one may calculate the upper limit of the anticyclone. From this it appears that this limit is less than 2,000 m. during the greater portion of the year, or that it lies below the mean level of the south polar continent. Accordingly there must be extensive areas of Antarctica that always lie higher than the level of the anticyclone and reach up into the levels of the polar cyclonic whirl which dominates the upper air strata of the higher latitudes wherein there is a general west-to-east air movement.

Figure 5 presents a diagrammatic cross section of the South Polar regions. The curved lines show the course of the isobars at various altitudes. In the vicinity of the South Pole the isobars of the lower layers are arched upward, as is characteristic of an anticyclonic distribution. In the upper layers, above 2,000 m., this arching is absent; in place of it the isobars sag toward the vicinity of the pole in accord with the cyclonic distribution of the "polar whirl." In the district of the anticyclone the air movement is prevailing easterly, but with southerly components; in the district of the cyclone it is westerly, with northerly components.

In figure 5 the arrows show only the meridional components of the winds; in addition the shaded area shows the region of easterly winds. If there were no land masses about the South Pole (the vertically exaggerated profile of figure 5 is quite arbitrary) then we might assume easterly winds would prevail over all the district of the anticyclone. The actual continent, however, permits only a portion of the anticyclone and the easterly winds to appear; and the land rises even into the overlying cyclone and westerly winds.

The boundary between the easterly and the westerly winds (shaded and unshaded portions of the figure) ascends from sea level at latitude 65° S. to meet the land at different latitudes and altitudes, depending upon the local topography. Where the general surface rises rapidly in relatively low latitudes, as at the right of figure 5, there is the least space for the easterly winds to develop; this seems to be the case in East Antarctica and particularly in Wilkes and Victoria Lands. (See figs. 2 and 4.) Where the coast retreats poleward and the back country rises slowly, there the region of the easterly winds is more extensive, as over Ross Sea. Figure 5 shows the supply of moisture to the polar district by poleward-pointing wind arrows; but there is also a vapor supply and condensation at the boundary between westerly and easterly winds in the latter district, as has been explained above. The following observational facts lend support to the scheme presented in figure 5.

The direction of the air currents at the upper cloud layer is seen by inspection of figure 4. In the upper layers the wind follows the isobars, approximately, and in such a manner that in the Southern Hemisphere they have the low center on the right hand. The probable course of the isobars has thus been drawn from the available antarctic observations on clouds and bear these facts in mind. In addition, it has been recognized that Shackleton and Amundsen met with southerly winds on the Antarctic Plateau.

When one studies the upper level isobars and winds, as thus restored, it seems not difficult to explain the sustenance of the inland ice within the nucleus of Antarctica; for it appears that in the sphere of the upper polar whirl there is an inflowing current of air and water vapor. The observations of the upper clouds at the marginal stations justify the conclusion that there is an intake of air at higher levels over the district between Weddell Sea and Wilkes Land, i. e., on the Indo-Atlantic side of the South Polar regions; and perhaps a similar intake over the district east of Ross Sea to the vicinity of the *Belgica* drift journey. Consequently the principal importation of water vapor will take place on this side of the South Polar region. Where the inflowing air strikes against mountain ranges it will be compelled to give up the aqueous vapor it is carrying. The region between Weddell Sea and Wilkes Land is heavily glaciated, as is also King Edward VII Land farther east; perhaps this is the reason for the glaciation. The compensating outflow of the now moisture-poor air seems to take place, on the other hand, chiefly on the west side of Ross Sea and of Weddell Sea. Here the upper winds are frequently from the south or southwest, and the stormy southwest winds of Snow Hill also indicate a lively exportation of air from the Antarctic region.

The very dry air peculiar to the west side of Ross Sea, and which makes itself felt as a characteristic peculiarity of the climate, may then perhaps be explained as the result of this district lying in the lee of Victoria Land and of East Antarctica in general. The westerly currents of the polar whirl, deprived of their moisture by the heights of East Antarctica, attain this district in a desiccated condition which still characterizes them when they leave the south polar regions. The stormy southwest winds of Snow Hill are also extraordinarily dry, yet of such a low temperature as is only to be explained if they descend from some great reservoir of cold, viz, the high-lying central portions of Antarctica.

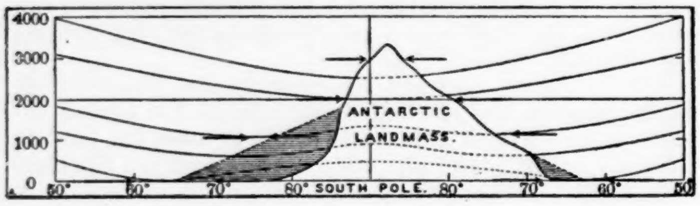

FIG. 5.—Diagrammatic cross section of the south polar regions, to show the position of the isobaric surfaces and the direction of the winds. Arrows show the meridional components of the wind; shaded areas show the region of prevailing easterlies Altitudes in meters.

This concept that the fixed land masses of the south polar regions are of considerable altitude, that they extend up into a suprapolar cyclonic whirl, thus solves in a general way tne difficulty of accounting for the ice-covered condition of central Antarctica. It must be the task of future expeditions to secure the detailed foundations for the hypothesis and particularly to reveal the secrets of the upper air over the nucleus of the south polar continent. Far-reaching conclusions will be founded upon this exploration, for in this way it will become possible to secure more intimate knowledge of the processes which promoted the growth of the great inland ice sheets over Canada and Scandinavia in the glacial period. These ancient ice sheets also reached considerable altitudes, and presumably rose above the zone of anticyclonic circulation. It will be in this domain of comparative climatology that future antarctic explorations will yield the most valuable results.

The observation and recording of the marginal movements of the inland ice of Antarctica will be of great importance in judging secular variations in climate. These movements and the magnitude of the ice discharge furnish a very sensitive scale for measuring the secular changes in distribution of precipitation. The great extent of the ice-covered area here smooths out both local differences and transitory anomalies in weather. Only the great and enduring climatic changes, whether periodic or nonperiodic in character, can find any expression in the thickness and velocity of the inland ice. One of the most imperative needs in future antarctic exploration thus seems to be continuous observations of the movements of the inland ice at the largest possible number of stations along its margin.

C. G. S. UNITS IN THE ENGLISH DAILY WEATHER REPORT.

In the MONTHLY WEATHER REVIEW for February, 1914, page 100, Dr. W. N. Shaw mentioned that beginning with the issue for May 1, 1914, the Meteorological Office would extend the use of C. G. S. units of pressure to its Daily Weather Report.

The transition to the new unit is facilitated for the user of the British Daily Weather Report by a table on the first page, which presents the adopted equivalent reduced readings in inches of a mercurial barometer at latitude 45°. Further help is offered on the inside pages by a graphic scale comparing the reduced mercurial barometric readings in inches with the millibars used on the adjacent maps. On the daily charts themselves the isobars are drawn for intervals of 5 millibars, but they are numbered in centibars, and the old-style readings in inches are entered at one end of the line. At first it may cause a slight inconvenience to find the tabulated reports on pages 1 and 4 presenting the pressures in millibars and the 24-hour change in "half-millibars" while the charts use centibars; but no doubt the habitual readers of the Report will soon become familiar with this demonstration of the great convenience of a rational decimal system of notation.

In this connection it is interesting and encouraging to note that simultaneously with the change to Bjerknes's "millibar" comes the change to "millimeter" in the column headed Rainfall. It gives us grounds for hope that eventually the English-speaking races may also adopt a thermometric scale that will combine all the advantages of the Fahrenheit and the centigrade scales.

Recent discussions in the United States make it of special interest to remark here that the continuance of the Beaufort scale of wind force still seems justified in the present improved Daily Weather Report.

In the following paper the Weather Bureau presents its recently adopted standard tables for converting standard barometric readings into millibars.—[C. A., jr.]

CONVERSION OF BAROMETRIC READINGS INTO STANDARD UNITS OF PRESSURE.

By ROY N. COVERT.

[Dated Instrument Division, Weather Bureau, May 8, 1914.]

Atmospheric pressures may be expressed in several different ways, viz, as heights in inches, or millimeters, of the barometric column of mercury or other suitable liquid; as pounds per square inch or grams per square centimeter of the weight of that column of mercury; or in absolute units of force.

Values expressed in one way are convertible into values expressed in each of the other ways. The conversion of atmospheric pressures, expressed in terms of the linear height of the mercurial column, into the form commonly used in engineering work, i. e., pressures expressed as a weight per unit area, requires a knowledge of the density of the mercury or liquid employed. The equation for this conversion is—

$$P = h\rho, \tag{1}$$

where P=pressure expressed as a weight per unit area,
h=height of the column in linear units,
ρ=density of the liquid, i. e., the mass of a unit volume at a standard temperature.

The conversion of pressure when expressed in linear units of the height of the mercurial column into dynes per square centimeter or millibars requires values for both the density of mercury, ρ, and the acceleration of gravity, g. The equation which gives the pressure in millibars, P_{mb}, corresponding to the barometric height, h, is—

$$P_{mb} = h\frac{\rho g}{1000} \tag{2}$$

When the Weather Bureau began the publication of the Daily Weather Map of the Northern Hemisphere, on January 1, 1914, and it was decided to express the pressure data in dynamic units, one bar being equal to 1,000,000 dynes, the bureau used the conversion tables prepared by Bjerknes and Sandström, giving the millibar equivalents of barometric readings made in inches or millimeters of pure mercury. The values for gravity (980.617) and for the density of mercury (13.59545) used by these writers[1] in computing their tables differed slightly from generally recognized values, therefore new tables based on the revised constants have been computed for the range of pressures necessary in the map work, and these went into effect with the issue for May 1, 1914. The new values for gravity and for the density of mercury were furnished by the United States Bureau of Standards, Washington, D. C., and are as follows:

$g = 980.665$ dynes,
$\rho = 13.59593$ grams per cubic centimeter (adopted by International Bureau of Weights and Measures).

The height of a column of pure mercury at a temperature of 0° C. and under normal gravity, that will exert a pressure of 1 bar will, therefore, by equation (2) be—

$$\frac{1000}{\rho g} = 75.0016 \text{ centimeters.}$$

We also obtain from equation (2) the following equation for converting barometric heights h, in millimeters, into pressure in millibars, P_{mb},—

$$P_{\text{mb}} = 1.333305h \text{ millimeters.}$$

Since 1 inch equals 1/0.03937 millimeter, the pressure in millibars corresponding to a pressure in inches, h', is

$$P_{\text{mb}} = \frac{1.333305}{0.03937} h',$$

$$= 33.86602\, h' \text{ inches.}$$

Below are given barometric readings in both inches and millimeters of mercury with their equivalents in millibars.

TABLE 1.—*Barometric inches into millibars.*

Inches.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	Mb.	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*
0.0	0.00	0.34	0.68	1.02	1.35	1.69	2.03	2.37	2.71	3.05
0.1	3.39	3.73	4.06	4.40	4.74	5.08	5.42	5.76	6.10	6.43
0.2	6.77	7.11	7.45	7.79	8.13	8.47	8.81	9.14	9.48	9.82
0.3	10.16	10.50	10.84	11.18	11.51	11.85	12.19	12.53	12.87	13.21
0.4	13.55	13.89	14.22	14.56	14.90	15.24	15.58	15.92	16.26	16.59
0.5	16.93	17.27	17.61	17.95	18.29	18.63	18.96	19.30	19.64	19.98
0.6	20.32	20.66	21.00	21.34	21.67	22.01	22.35	22.69	23.03	23.37
0.7	23.71	24.04	24.38	24.72	25.06	25.40	25.74	26.08	26.42	26.75
0.8	27.09	27.43	27.77	28.11	28.45	28.79	29.12	29.46	29.80	30.14
0.9	30.48	30.82	31.16	31.50	31.83	32.17	32.51	32.85	33.19	33.53
1.0	33.87	......	......	......	......	......	......	......	......	......

[1] Bjerknes, V., and others. Dynamic meteorology and hydrography. Part 1. Washington. 1910. p. 7. (Carnegie instit. of Wash'n. Publication 88.)

TABLE 2.—*Barometric inches into millibars.*

Inches.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
	Mb.	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*
28.0	948.2	948.6	948.9	949.3	949.6	949.9	950.3	950.6	951.0	951.3
28.1	951.6	952.0	952.3	952.6	953.0	953.3	953.7	954.0	954.3	954.7
28.2	955.0	955.4	955.7	956.0	956.4	956.7	957.1	957.4	957.7	958.1
28.3	958.4	958.7	959.1	959.4	959.8	960.1	960.4	960.8	961.1	961.5
28.4	961.8	962.1	962.5	962.8	963.1	963.5	963.8	964.2	964.5	964.8
28.5	965.2	965.5	965.9	966.2	966.5	966.9	967.2	967.6	967.9	968.2
28.6	968.6	968.9	969.2	969.6	969.9	970.3	970.6	970.9	971.3	971.6
28.7	972.0	972.3	972.6	973.0	973.3	973.6	974.0	974.3	974.7	975.0
28.8	975.3	975.7	976.0	976.4	976.7	977.0	977.4	977.7	978.0	978.4
28.9	978.7	979.1	979.4	979.7	980.1	980.4	980.8	981.1	981.4	981.8
29.0	982.1	982.5	982.8	983.1	983.5	983.8	984.1	984.5	984.8	985.2
29.1	985.5	985.8	986.2	986.5	986.9	987.2	987.5	987.9	988.2	988.5
29.2	988.9	989.2	989.6	989.9	990.2	990.6	990.9	991.3	991.6	991.9
29.3	992.3	992.6	992.9	993.3	993.6	994.0	994.3	994.6	995.0	995.3
29.4	995.7	996.0	996.3	996.7	997.0	997.4	997.7	998.0	998.4	998.7
29.5	999.0	999.4	999.7	1,000.1	1,000.4	1,000.7	1,001.1	1,001.4	1,001.8	1,002.1
29.6	1,002.4	1,002.8	1,003.1	1,003.4	1,003.8	1,004.1	1,004.5	1,004.8	1,005.1	1,005.5
29.7	1,005.8	1,006.2	1,006.5	1,006.8	1,007.2	1,007.5	1,007.9	1,008.2	1,008.5	1,008.9
29.8	1,009.2	1,009.5	1,009.9	1,010.2	1,010.6	1,010.9	1,011.2	1,011.6	1,011.9	1,0 2.3
29.9	1,012.6	1,012.9	1,013.3	1,013.6	1,013.9	1,014.3	1,014.6	1,015.0	1,015.3	1,015.6
30.0	1,016.0	1,016.3	1,016.7	1,017.0	1,017.3	1,017.7	1,018.0	1,018.3	1,018.7	1,019.0
30.1	1,019.4	1,019.7	1,020.0	1,020.4	1,020.7	1,021.1	1,021.4	1,021.7	1,022.1	1,022.4
30.2	1,022.8	1,023.1	1,023.4	1,023.8	1,024.1	1,024.4	1,024.8	1,025.1	1,025.5	1,025.8
30.3	1,026.1	1,026.5	1,026.8	1,027.2	1,027.5	1,027.8	1,028.2	1,028.5	1,028.8	1,029.2
30.4	1,029.5	1,029.9	1,030.2	1,030.5	1,030.9	1,031.2	1,031.6	1,031.9	1,032.2	1,032.6
30.5	1,032.9	1,033.3	1,033.6	1,033.9	1,034.3	1,034.6	1,034.9	1,035.3	1,035.6	1,036.0
30.6	1,036.3	1,036.6	1,037.0	1,037.3	1,037.7	1,038.0	1,038.3	1,038.7	1,039.0	1,039.3
30.7	1,039.7	1,040.0	1,040.4	1,040.7	1,041.0	1,041.4	1,041.7	1,042.1	1,042.4	1,042.7
30.8	1,043.1	1,043.4	1,043.7	1,044.1	1,044.4	1,044.8	1,045.1	1,045.4	1,045.8	1,046.1
30.9	1,046.5	1,046.8	1,047.1	1,047.5	1,047.8	1,048.2	1,048.5	1,048.8	1,049.2	1,049.5
31.0	1,049.8	1,050.2	1,050.5	1,050.9	1,051.2	1,051.5	1,051.9	1,052.2	1,052.6	1,052.9
31.1	1,053.2	1,053.6	1,053.9	1,054.2	1,054.6	1,054.9	1,055.3	1,055.6	1,055.9	1,056.3
31.2	1,056.6	1,057.0	1,057.3	1,057.6	1,058.0	1,058.3	1,058.6	1,059.0	1,059.3	1,059.7
31.3	1,060.0	1,060.3	1,060.7	1,061.0	1,061.4	1,061.7	1,062.0	1,062.4	1,062.7	1,063.1
31.4	1,063.4	1,063.7	1,064.1	1,064.4	1,064.7	1,065.1	1,065.4	1,065.8	1,066.1	1,066.4
31.5	1,066.8	1,067.1	1,067.5	1,067.8	1,068.1	1,068.5	1,068.8	1,069.1	1,069.5	1,069.8
31.6	1,070.2	1,070.5	1,070.8	1,071.2	1,071.5	1,071.9	1,072.2	1,072.5	1,072.9	1,073.2
31.7	1,073.6	1,073.9	1,074.2	1,074.6	1,074.9	1,075.2	1,075.6	1,075.9	1,076.3	1,076.6
31.8	1,076.9	1,077.3	1,077.6	1,078.0	1,078.3	1,078.6	1,079.0	1,079.3	1,079.6	1,080.0
31.9	1,080.3	1,080.7	1,081.0	1,081.3	1,081.7	1,082.0	1,082.4	1,082.7	1,083.0	1,083.4
32.0	1,083.7	......	......	......	......	......	......	......	......	......

TABLE 3.—*Barometric millimeters into millibars.*

Millimeters.	0	1	2	3	4	5	6	7	8	9
	Mb.	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*	*Mb.*
710	946.6	948.0	949.3	950.6	952.0	953.3	954.6	956.0	957.3	958.6
720	960.0	961.3	962.6	964.0	965.3	966.6	968.0	969.3	970.6	972.0
730	973.3	974.6	976.0	977.3	978.6	980.0	981.3	982.6	984.0	985.3
740	986.6	988.0	989.3	990.6	992.0	993.3	994.6	996.0	997.3	998.6
750	1,000.0	1,001.3	1,002.6	1,004.0	1,005.3	1,006.6	1,008.0	1,009.3	1,010.6	1,012.0
760	1,013.3	1,014.6	1,016.0	1,017.3	1,018.6	1,020.0	1,021.3	1,022.6	1,024.0	1,025.3
770	1,026.6	1,028.0	1,029.3	1,030.6	1,032.0	1,033.3	1,034.6	1,036.0	1,037.3	1,038.6
780	1,040.0	1,041.3	1,042.6	1,044.0	1,045.3	1,046.6	1,048.0	1,049.3	1,050.6	1,052.0
790	1,053.3	1,054.6	1,056.0	1,057.3	1,058.6	1,060.0	1,061.3	1,062.6	1,064.0	1,065.3
800	1,066.6	......	......	......	......	......	......	......	......	......

THE BEAUFORT WIND SCALE.

The Weather Bureau is glad to profit by wise and practical suggestions, but occassional published items relative to the Beaufort wind scale, serve little useful purpose and leave the impression that their authors are not animated by the simple desire to serve the public at large. Not only has the Beaufort scale gradually come into use by observers both on land and sea, but every attempt to

dislodge it has seemed unwise. Even the International Permanent Committee on Meteorology has found nothing better for general use, although instruments may be at hand that will give the velocity in miles per hour at any spot where an anemometer happens to be established. The officials of all Government weather bureaus have suggested their various substitutes for the Beaufort scale, and numerous alterations have thus been made in the terms and definitions recommended to public use, but the Beaufort wind scale has not yet been given up.

The introduction of such alterations in the definitions of ordinary well-known English words has led to great confusion of records and usages. Our own daily weather charts are widely known over the world and local terms should be avoided. It is better to adhere to the terms and corresponding velocities of the well-known Beaufort scale when one has no freely exposed velocimeter or anemometer. There has been great improvement in anemometers, but that does not justify us in departing from the Beaufort scale for the use of the millions who have no such apparatus.

There have been many efforts to establish a scale of *ten* terms from calm to hurricane, as recommended by the International Meteorological Committee in 1873 and 1874; various scales have been suggested of nine, eight, seven, six, and four terms, respectively, and there have been numerous attempts to reduce each of these to the simple fundamental Beaufort scale of twelve terms, but the latter is still used. Nine fundamental terms of that original scale, i. e., calm, light, fresh, breeze, brisk, high, gale, storm, hurricane, and their additional modifications by the words gentle, moderate, strong, have proved to be sufficient for ordinary use, both at sea and on land. These terms are in ordinary use by English-speaking observers, as well as many other nations, all over the world; they are well defined in any modern dictionary, thereby forbidding any educated person from complaining that the terms are not understood. Those newspapers and correspondents who wish these terms translated into miles per hour should consult the ordinary popular works on meteorology. In general, it is sufficient to know that a moderate gale means a wind having a velocity of 35 to 45 miles per hour, from which we may count upward or downward, without any expensive apparatus.

The adoption of the Beaufort scale in 1905 by the instructions of the former chief of the Weather Bureau, as also its continued usage by the orders of the present chief in 1914, assure us that there is good reason for its general use. If one has no anemometer and wishes to use a 10-scale, he may group the latter part of the Beaufort and call that the end or No. 10 of his own scale.

We note that lately the British Meteorological Office has adopted as definitions of the respective terms of the Beaufort scale the approximate equivalent values in meters per second. These are here given for the information of the reader; and the comparison between all these shows that while retaining the terms of the Beaufort scale, there have also been great differences between those who have attempted to convert it into observed velocity or pressure.

Adopted velocities.

Beaufort wind scale.		Meters per second.	Miles per hour.	
No.	Terms.	Hann.	Milham.	Weather Bureau, Feb., 1914.
0	Calm	Calm.	0	0 to 3
1	Light air	1.7	3	3 to 8
2	Light breeze	3.1	13	8 to 13
3	Gentle breeze	4.8	18	13 to 18
4	Moderate breeze	6.7	23	18 to 23
5	Fresh breeze	8.8	28	23 to 28
6	Strong breeze	10.7	34	28 to 34
7	Moderate gale	12.9	40	34 to 40
8	Fresh gale	15.4	48	40 to 48
9	Strong gale	18.0	56	48 to 56
10	Whole gale	21.0	65	56 to 65
11	Storm	30	75	65 to 75
12	Hurricane	50	90	75 or over.

As used by British Meteorological Office.

Beaufort No.	Miles per hour.	Meters per second.	Feet per second.	Pressures.[1]	
				Pounds per square foot.	Millibars.
0	Less than 1	Less than 0.3	Less than 2	0.00	0.00
1	1-3	0.3-1.5	2-5	0.01	0.01
2	4-7	1.6-3.3	6-11	0.08	0.04
3	8-12	3.4-5.4	12-18	0.28	0.13
4	13-18	5.5-8.0	19-27	0.67	0.32
5	19-24	8.1-10.7	28-36	1.31	0.62
6	25-31	10.8-13.8	37-46	2.3	1.1
7	32-38	13.9-17.1	47-56	3.6	1.7
8	39-46	17.2-20.7	57-68	5.4	2.6
9	47-54	20.8-24.4	69-80	7.7	3.7
10	55-63	24.5-28.4	81-93	10.5	5.0
11	64-75	28.5-33.5	94-110	14.0	6.7
12	Above 75	33.6 or above.	Above 110	17.0 or over.	8.1 or over.

[1] These figures are computed for air of standard density; they diminish as we ascend in the atmosphere, they increase with the momentum of any rain that is driven with the wind.—[C. A.]

ICE PATROL OVER THE NORTH ATLANTIC OCEAN.

By Edward H. Bowie, District Forecaster.

[Dated United States Weather Bureau, Washington, May 13, 1914.]

Commissioners appointed by the several nations to make recommendations concerning "The safety of life at sea" held meetings at London, England, during the period November 12, 1913, to January 20, 1914, and, besides adopting regulations concerning the equipment of vessels, etc., proposed a patrol of the North Atlantic Ocean in the region of the steamer routes for the observation and study of ice conditions and for the destruction of derelicts. Each nation that was a party to the commission agreed to bear its proportionate part of the expenses of the patrol and the United States was invited to inaugurate and maintain such a service in 1914 in the following language:

> The Government of the United States is invited to undertake the three services of derelict destruction, study and observation of ice conditions, and ice patrol, etc.

During the spring and early summer of 1913, previously to the meeting of the commission, work of this character was conducted by the S. S. *Scotia*. During the present year, however, the work is being conducted by the revenue

cutter *Seneca*, in accordance with the recommendations of the commission. Besides being equipped for a study of ice conditions and securing data regarding the direction, speed, and temperature of the ocean currents, the *Seneca* has also a meteorological outfit, and observations will be be taken several times daily of the barometer, temperature, wind direction, state of the weather, and force of the wind. The 4 a. m. observation is embodied with other information in a radiogram sent each day to New York, and the meteorological observation is thence transmitted to Washington for use on the Northern Hemisphere Weather Chart. The first message of this character was received April 9. The reports from the *Seneca* are usually received in time to be published in the table on the Northern Hemisphere Weather Map.

The work done by the S. S. *Scotia* in 1913 is of great interest to meteorologists. Among the observations taken are the following:

(1) The taking of water samples by means of the full-speed water bottle when the ship is moving and by means of the insulating or reversing bottle at various depths when the ship is stationary. The samples are used in obtaining the salinity of the water and also in connection with the plankton investigations, about which something will be said later. The value of the water samples depends not only on the differences in salinity which show the boundaries between the various currents, but also on the differences in density when temperature is taken into consideration, as from these latter it is possible to calculate dynamically the differences of current flow.

(2) The ordinary surface net and the full-speed tow net were used in obtaining samples of plankton at the surface and at depths down to 30 fathoms or more for use in studying the distribution of these minute forms of plant life in connection with the temperature and salinity. In the report of the work done by the S. S. *Scotia* during 1913 reference was made to certain samples which showed strongly marked horizontal and vertical thermal and biologic boundary lines. These boundaries seem to limit bodies of water apparently of polar and southern origin respectively. An examination of the plankton contained in the water frequently enables one to identify the source of the strata of water forming the different currents by reason of the fact that the distribution of the definite species is largely determined by the different degrees of salinity and temperature.

(3) Ocean currents at various depths and ice-drift measurements were made.

(4) Water temperatures were measured by the ordinary water thermometers at different depths and the Callendar-Barnes self-recording thermometer was also used. No rise in temperature was noted on approaching icebergs.

(5) Air temperatures were observed with standard thermometers and recorded on a thermograph. In this connection 13 successful kite flights were made, although with difficulty, it being found difficult to get the kites away from the ship with success owing to the wind eddies caused by the spars and rigging of the ship. On one occasion, in the midst of a fog, a captive balloon was sent up to an altitude of 3,500 feet, records of temperature and humidity being obtained. On 8 flights made during foggy weather an inversion of temperature was in each case noted. But fog did not prevail with all inversions of temperature. However, all marked inversions were recorded during fogs, but slight inversions occurred without fog. Comparative wind velocities at 45 and 70 foot levels showed that velocities at the 70-foot level were greater by about 7 per cent than those at the 45-foot level. Hygrometric observations were made with the hair hygrometer and the wet and dry bulb thermometers. The height and direction of seas and swells and the density of fog were also noted.

Similar atmospheric observations and studies will be made during the season of 1914, and it is hoped that by studying the ocean currents their relation to the extent and time of the southward drift of the icebergs may be determined.

A LAKE HURON CURRENT.

In a letter [dated May 4, 1914] from Mr. John D. Persons, relative to the stranding of the steamer *Acadian* he says:

You ask me some questions in regard to the stranding of the steamer *Acadian* on Sulphur Island, November 9-11, 1913. "Was it due to the influence of some unknown strong current? Are not the local currents in Lake Huron during strong winds well known?"

When I was a young man I was in the fishing business; it was there that I first learned that a strong current at times sets down the west shore of Lake Huron, into Saginaw Bay. After I came into the Life-Saving Service, being located on the turning point of Lake Huron, Thunder Bay Island, I soon began to notice that shipping was affected by this current. Steamers coming up the lake, crossing from Point Aux Barques to this Island in smoky and thick weather, would all fetch up from 1 to 3 miles behind this island, from 6 to 10 miles off their regular compass course. Not one boat, but all boats during that day would be affected by that current. Fishermen suffer a great deal by this current, as it sweeps their buoys under so they can not find their nets. The writer has seen the ice fields going down the lake much faster than a man could walk, and not a breath of wind.

During my 36 years as keeper of this station I attribute many strandings that have occurred in this vicinity in thick weather to this unknown current. A steamer crossing from Point Aux Barques to Thunder Bay Island, a distance of 75 miles, with a strong current striking her on the starboard side must move sideways to some extent.

You ask me if this current is not well known. No, only to the fishermen and tug men that have been rafting and towing saw logs. So far as I am informed this current is not strong enough to be observed, only on certain occasions. As far as my observation goes, the wind has nothing to do with it at certain times, runs very strong at times with no wind. A question. If the water fell 2 or 3 feet along the west shore of Thunder Bay November 9, and rose 3 or 5 feet at Port Huron what would be the result? Would not that water set into Saginaw Bay strong enough to carry the *Acadian* sideways off her course several miles? Her cargo did not shift nor were there any irregularities of her compass.

Mr. Frank Jermin and myself are making quite a study of this matter and we are in hopes to have something to place before the Weather Bureau office at no distant day.

PROPOSED ASIATIC EXTENSION OF THE RUSSIAN WEATHER SERVICE.

John F. Jewell, United States consul at Vladivostok, advises us through the State Department, under date of April 17, 1914, as follows:

The Vladivostok Observatory has worked out and submitted to the Duma at St. Petersburg for approval a plan to organize a weather service in the Russian Far East. The plan proposes—

1. To establish 20 meteorological stations in the most important places, the construction to be completed within four years.
2. To establish special parallel stations at different altitudes, for the purpose of securing observations at differently exposed points under the same latitude; the construction to be completed within five years.
3. To make regular observations of the warm current called the Kuroshiwo, or the Japan Current.
4. To maintain a telegraphic branch at Vladivostok.

It is estimated that the total cost of installation and upkeep until completion will be 254,000 rubles ($130,810). As this meteorological system and its synoptical service develop the Vladivostok Observatory will undertake to notify the country population of approaching weather changes. It is intended to gradually enlarge the organization until it embraces the whole of the Russian Far East.

NOTES.

The following brief record of recent events in the history of Blue Hill Meteorological Observatory supplements the note on the same subject in the REVIEW for March, 1914, page 183. The information is taken from the "Reports of the president and treasurer of Harvard College, 1912-13," Cambridge, Mass., 1914, pages 16, 167, 203; treasurer's statement, page 17.

The observatory was bequeathed to Harvard University by Abbott Lawrence Rotch, who died on April 7, 1912. The formal transfer of the observatory took place in March, 1913, and at the same time the university received from the donor's estate $50,075, the income from which is "to be used and applied for the purpose of maintaining upon the premises [on Great Blue Hill] a meteorological observatory and of making, recording, and reducing meteorological observations and publishing the results thereof in connection with the Harvard College Observatory * * *." Mrs. Rotch has liberally supplemented the income from this fund, so that it has been possible to appoint Alexander George McAdie as Abbott Lawrence Rotch professor of meteorology and director of the Blue Hill Observatory. Prof. McAdie entered upon his duties just before the opening of the academic year 1913-14.

The library remains housed at the observatory on the summit of Great Blue Hill, but is now a constituent part of the Harvard University library soon to move into its new building. Prof. Rotch left a well-chosen collection of books intended for those engaged in research work in meteorology, climatology, and aerodynamics, amounting to 7,900 volumes and 14,950 pamphlets. The founder had given special attention to the acquisition of standard treatises, rare issues, and volumes of exceptional merit and interest.

The Editor is requested to state that after May 1, 1914, the address of the International Commission for Scientific Aeronautics will be "c/o K. Preuss. Aeronautisches Observatorium, Lindenberg bei Beeskow, Germany." This will also be the address of Prof. Dr. H. Hergesell, president of the International Commission, as he has recently been appointed director of the Aeronautical Observatory.

SECTION III.—FORECASTS.

STORMS AND WARNINGS FOR APRIL.

By H. C. FRANKENFIELD, Professor of Meteorology.

[Dated U. S. Weather Bureau, Washington, May 7, 1914.]

At the beginning of the month the low pressure over the upper Lake region and the Ohio Valley was causing general rains over much of the eastern half of the country. Temperatures were moderate over the southern districts, and high over the northern, while over the western half of the country pressure was comparatively high with fair weather and nearly normal temperatures. The Lake storm continued eastward with rapidly increasing intensity and on the morning of the 2d was central over the Maine coast, the barometer at Eastport, Me., reading 29.16 inches. Small-craft warnings were ordered for the New England and Middle Atlantic coasts, and winds occurred as forecast. Rains had continued in the Ohio Valley and the Lake region, changing to snow over Lake Superior, eastern Lake Erie, and Lake Ontario, and had extended through New England with strong west to north winds and with snow over the northern portion. It was much warmer in the Atlantic States, and colder in the Lake region and the Ohio Valley. To the westward the weather was fair with high pressure and moderate temperature, except on the north Pacific coast, where the barometer was again falling with local rains that extended eastward into western Montana. At 6:40 p. m. storm warnings were ordered along the Washington and Oregon coasts.

Frost warnings on the 1st and 2d for Missouri, Kansas, Arkansas, Oklahoma, and Texas failed of verification owing to the fact that the recovery from the eastern disturbance was very slow from the upper Mississippi Valley eastward, and cool and unsettled weather with rains and snows continued until the morning of the 4th, by which time the western high area had overspread the East, and killing frosts and freezing temperatures occurred as far south as Tennessee, warnings for which had been issued on the morning of the 3d. A depression that was over the southern coast of California on the morning of the 1st, had by this time reached the mouth of the Rio Grande, and rains were falling over Oklahoma, Texas, and New Mexico. The disturbance on the north Pacific coast had also continued to increase with resulting rains in the Coast States, except southern California. Over the interior West the weather remained fair, with temperatures somewhat below the seasonal average, as a rule. A very moderate depression had also appeared to the northeastward of Lake Superior; it moved eastward without developing any intensity of consequence, but it caused a resumption of rains and snows from the Lake region eastward to New England, and it was followed by another fall in temperatures that brought them well below the freezing point from the upper Mississippi Valley eastward by the morning of the 5th. By this time also the north Pacific disturbance had moved into the Middle Plateau and the rain area had extended into Idaho, Nevada, and south California. Pressure was rising rapidly behind this low with a decided fall in temperature.

By the morning of the 6th the Plateau disturbance had moved to the Texas Panhandle with increased intensity, and an arm of disturbance extended northeastward to southern Lake Michigan. This, with a cool high area to the northward, resulted in quite general rains and snows in the Rocky Mountain region, the Plains States, the Missouri and upper Mississippi Valleys, and the upper Lake region. In the East and South pressure was high with generally clear weather and low temperature, and with frosts once more as far south as Tennessee and North Carolina. West of the Rocky Mountains the weather had generally cleared, and frosts occurred in the north Pacific States, with a recurrence on the following morning, both as anticipated. On the morning of the 7th the depression extended in parabolic shape from Texas northeastward to Ohio, but with diminishing intensity, and the barometer was rising rapidly to the northward and northwestward, with temperatures ranging from 10 to 30°. Small-craft warnings were ordered for the Texas coast. Rains and snows had continued from the Rocky Mountain region eastward to the Mississippi River and the upper Lake region, and had extended through the Ohio Valley and the lower Lake region into the Middle Atlantic States and New England. Pressure was high over the middle Atlantic Ocean, and temperatures had risen decidedly in the Ohio Valley, Middle Atlantic States, and the South. West of the Rocky Mountains the weather was generally clear with moderate temperatures. The western depression drifted slowly eastward with several independent centers of circulation, and on the morning of the 8th it extended from western Florida northeastward through New York, with general rains and snows east of the Mississippi River, with continued high temperatures in the Atlantic States, and abnormally low ones in the Plains States, the Southwest, the Central Valleys, and the Lake region—the line of freezing temperature extending into northern Texas. As this disturbance gave some promise of further development, small-craft warnings were ordered in the evening of the 7th for the New England and Middle Atlantic coast, the warnings to be displayed on the following morning, at which time similar warnings were ordered for the Louisiana coast. With the exception of some snows in the Rocky Mountain region, the weather was generally clear in the West, but with falling pressure in the extreme West and a tendency toward rising temperatures.

As the barometric gradient was quite steep, northwest storm warnings were ordered at 2:30 p. m. on the Gulf coast from Pensacola to Cedar Keys, Fla., and on the Atlantic coast from Jacksonville, Fla., to Boston, Mass., and moderate to strong winds prevailed during the succeeding 24 hours. During the 8th the disturbance contracted somewhat and by the morning of the 9th there was but a single center over the lower St. Lawrence Valley. Rains and snows had continued in the Lake region, New England, and the Middle Atlantic States, and rains in the South with a decided fall in temperature to much below the normal conditions. Cold weather also continued in the Central Valleys and the Gulf States with freezing temperatures into central Texas, warnings for which had been issued on the previous day. Warnings of frost for

the Carolinas and Georgia failed of verification on account of the persistence of cloudy weather. The high pressure area covered the central and southwestern portions of the country, and its eastward drift necessitated additional frost warnings for the Ohio Valley, the Middle Atlantic States, and the South generally, except eastern and southern Florida. Frosts occurred as forecast on the morning of the 10th, when the high pressure and low temperatures covered the East and South, while another disturbance from the Canadian Northwest had reached Minnesota with greatly increased intensity, attended by light local snows from Minnesota westward. There was also another disturbance over the Middle Plateau, and the Pacific coast rains extended eastward to the mountains.

Advisory warnings were issued at 9 a. m. for moderate south to southwest gales on Lake Michigan, and during the afternoon southwest storm warnings were ordered for the southern California coast. By the evening of the 10th the plateau disturbance had moved to southeastern New Mexico with increased intensity and orders were issued to display small-craft warnings on the Texas coast on the following morning, by which time the disturbance was over Texas, while the northern disturbance had passed to the northeastward of Lake Superior attended by light rains and snows, moderate westerly gales, and higher temperatures. This condition of rising temperature covered practically the entire country except the Atlantic and the Pacific States, temperatures over these two latter districts continuing quite cool with light frost as far south as North Carolina. The weather had also been fair except over the region affected by the northern disturbance, but there was another disturbance of moderate character that had moved in from the Pacific coast since the night of the 9th and was central over Saskatchewan by the morning of the 12th. The northern disturbance had reached central Ontario, while the southern one was over the western Gulf of Mexico with resulting general showers from the Gulf States northeastward through Canada. Low temperatures continued quite generally, except in the Southeast, with a further fall over the region covered by the showers. Pressure was high over the central portion of the country with heavy to killing frosts, for which warnings had been issued on the previous morning. Pressure was also higher over the extreme West, with generally clear weather. No storm warnings had been necessary for the northern storm, but small-craft warnings were displayed during the 11th on the New England coast, and northwest storm warnings during the night of the 11th on the north New Jersey coast. Small-craft warnings had also been displayed on the middle Gulf coast for the fresh breezes caused by the Gulf disturbance.

Owing to the continued low temperatures and high pressure in the central West, frost warnings were repeated for those sections on the morning of the 12th and extended into the interior West Gulf States, the Ohio Valley, the north portions of the East Gulf States, and the Middle Atlantic States. Occurrences on the following morning justified these forecasts, except in so far as they related to the Gulf States where more or less cloudiness prevented the formation of frost. By this time (Apr. 13) the northern disturbance had passed off the Newfoundland coast with greatly increased intensity, and high pressure with low temperatures covered the entire eastern half of the country, except the South Atlantic and East Gulf States, where temperatures had not changed materially. A temperature reading of six degrees below zero was reported from White River, Canada, while freezing temperatures generally prevailed over the northern tier of States from Minnesota eastward. Over the West, pressure was falling with a disturbance approaching the north Pacific coast, and rains were falling in Idaho, Washington, Oregon, and northern California.

The disturbance that was over the western Gulf of Mexico on the 12th apparently reappeared during the 13th and, by the morning of the 14th, it had moved northeastward to Tennessee with increased intensity causing general and, in many places, heavy rains throughout Tennessee, the East Gulf and South Atlantic States, except Florida. Pressure had also fallen generally over the northern and western portions of the country, except the northern plateau, but without precipitation except some local rains in the Northwest and the North Pacific States. Temperatures were generally rising except in few localities. The southern storm did not present a very well-defined formation, but moved northeastward with two centers that, on the morning of the 15th, were over Kentucky and eastern North Carolina, respectively. Rains continued in the South and extended through the Ohio Valley and the southern portion of the Middle Atlantic States. Strong high pressure continued to the northeastward but no high winds had as yet occurred. In the West conditions had not changed materially, except that another disturbance from the Pacific had reached Alberta attended by general rains in the North Pacific States, including northern California, and temperatures had risen generally, except in the Northwest, although still below the seasonal average over the eastern half of the country. During the 14th northeast storm warnings had been ordered on the Atlantic coast from North Carolina to Cape Cod, Mass., and, on the morning of the 15th, for the balance of the New England coast. Moderately high winds occurred and the slow northeastward movement of the storm necessitated a continuance of the warnings on the night of the 15th from Delaware Breakwater to Cape Cod. They were, however, lowered on the morning of the 16th from Delaware Breakwater to New Haven, Conn., by which time the storm center was off the southern New England coast, still moving northeastward.

By the night of the 16th the northwestern disturbance had practically disappeared while the Middle West one had moved to western Kansas with increasing energy. As this latter disturbance appeared to be developing rapidly, southeast storm warnings were ordered at 10 p. m. for Lake Michigan, and small-craft warnings for the following morning on the Gulf coast. However, the western disturbance did not move eastward as fast as had been expected and by the morning of the 17th it was central over eastern Nebraska, and consequently no strong winds occurred on Lake Michigan. Although temperatures rose decidedly to the eastward and southward of the disturbance, there was no precipitation, except some local rains and snows in Colorado, Wyoming, and the Northwest. The eastern disturbance had moved to the Nova Scotia coast and the rains and snows in the lower Lake region, the Middle Atlantic States, and New England had practically ended. The extreme western high-pressure area had moved into the northern plateau attended by interior frosts over the north Pacific States and the plateau regions, for which warnings had been ordered on the 16th. The western storm developed more to the northeastward during the 17th and at 3:30 p. m. of that date northeast storm warnings were ordered on Lake Superior from Duluth to Marquette; and, as the western depression also dipped southward into Texas, small-craft warnings were ordered on the west Gulf coast at Galveston. Frost warnings were again repeated for the north

Pacific States, Utah, Colorado, and northern New Mexico and frosts occurred on the morning of the 18th as forecast. The western disturbance still continued its very slow east-northeast movement and it now extended from Minnesota southward to western Missouri with a moderate secondary disturbance near the mouth of the Rio Grande. Rains had begun to the eastward and southward extending from Texas to Lake Superior. There were also quite general rains in the Northwestern States and local snows and rains in the central Rocky Mountain region. As the western storm appeared to be developing, southwest storm warnings were ordered at 10 a. m. for Lakes Huron, Erie, and Michigan with instructions to change to northwest at sunset on Lake Michigan. At 3:30 p. m. northeast warnings on Lake Erie were changed to northwest and northwest warnings were also ordered for the remainder of Lake Superior. To the eastward and southward fair weather continued with high pressure and higher temperatures, while west of the Mississippi River—at least as far as the Rocky Mountains—temperatures were somewhat lower. The extreme western high area had moved into the interior over Idaho and western Montana, and the barometer was again falling rapidly over the extreme north Pacific coast with rains in that section.

During the afternoon of the 18th southwest storm warnings were extended to Lake Ontario and on the same evening southwest warnings were also ordered for the extreme north Pacific coast. On the morning of the 19th the storm center was over northern Lake Michigan with increased intensity (29.42 inches at Green Bay, Wis.). Rains and snows had fallen generally between the Mississippi River and the Allegheny Mountains and strong winds or moderate gales had occurred over the upper Lakes and on Lake Erie. The disturbance that was over the mouth of the Rio Grande had also moved northeastward to southwestern Alabama, causing general showers in the Gulf States, except interior Texas. Temperatures had risen decidedly in the New England and the Middle Atlantic States and the lower Lake region, where they were from 15 to 30 degrees above the seasonal average, while over the upper Lake region and the Central Valleys they had fallen decidedly and were again below the seasonal average between the Mississippi River and the Rocky Mountains. Storm warnings on Lake Huron were changed to northwest at 10:30 a. m. on the 19th and also continued on Lake Erie with instructions to change to northwest at sunset. Small-craft warnings were also ordered on the east Gulf coast for strong winds that would be caused by the disturbance over southeastern Alabama. As the northern storm had now developed a more active eastward movement, frost warnings were ordered for the Ohio Valley, Tennessee, northern Alabama, warnings of frost and freezing temperatures for Indiana, advisory warnings for snow and much colder weather for Michigan, and warnings of frost or freezing temperatures for Illinois and the entire central west. Frost and freezing temperatures occurred generally on the morning of the 20th as previously forecast, except in Kentucky, Tennessee, and northern Alabama, where unsettled cloudy weather persisted.

The disturbance that was noted over the extreme north Pacific coast on the morning of the 18th had by this time reached Saskatchewan with much increased development and with light rains in the Northwest, while the Middle West low area had reached the New England and the Middle Atlantic States with very indefinite development, but with general rains and snows east of the Mississippi River and with continued high temperatures in the Middle Atlantic and New England States. Small-craft warnings were ordered at 10 a. m. from Norfolk, Va., to Eastport, Me., and, as the disturbance gave promise of renewed development, northeast storm warnings were ordered at 9:30 p. m. for the eastern Maine coast, at which time the storm center was off the Massachussetts coast moving northeast. By the morning of the 21st the northeastern storm was off the Nova Scotia coast, but rains had continued in New England, the Middle Atlantic States, and the lower Lake region. Pressure was high over the Ohio Valley and the South, and frosts had occurred in Kentucky and Tennessee. It was considerably colder in the Atlantic States and the lower Lake region, warmer from the upper Lake region southwestward, and generally colder in the Northwest and the extreme West. The northern disturbance of the 20th had moved to Lake Superior with greatly decreased energy, while another of more marked character had developed over southern Nevada, the general depression extending eastward over Kansas and Nebraska, with a moderate high area to the northward that was causing local snows and rains in Montana, Wyoming, and Nevada. There had also been quite general frosts in the north Pacific States for which warnings had been issued on the 20th; these warnings were repeated on the 21st for the frosts that again occurred on the following day. Frost warnings were also issued on the morning of the 21st for Delaware, Maryland, east Pennsyvania, and Virginia; but they did not materialize generally on account of the southeastward movement of the Ohio Valley high-pressure area. On the morning of the 22d the northwestern high area was found to have developed considerably and, with its crest over northern Minnesota, was moving eastward after the Lake Superior low area that had moved to the lower St. Lawrence Valley with increased development, attended by local thundershowers in the Lake region. Pressure also continued high in the South with fair weather, except in east Texas, where general rains were falling with the southeast wind blowing from the Gulf of Mexico into the western disturbance, which by this time had reached northern Arizona. The general depression had also extended eastward in very moderate form, so that it reached between the two high areas with resulting unsettled weather but without precipitation of consequence.

On the morning of the 23d the western depression was central over eastern Colorado, with a secondary center over southern Alberta. The southern high area had lessened somewhat, while the northern one had increased materially and was central over northeastern Michigan with a crest of 30.62 inches. It caused a general and decided fall in temperature from the upper Ohio Valley and the upper Lake region eastward, while to the southward temperatures remained comparatively high. It was also much warmer in the Northwest and colder in the Middle Plateau and the extreme Southwest. The only precipitation of consequnce covered a narrow belt extending from east Texas northward to the Canadian line. On the morning of the 24th the principal storm center had moved to northwestern Iowa, while the northern secondary one had moved to western North Dakota; this had resulted in the extension of the rain area eastward through the upper Lake region, and weather had become cloudy and unsettled throughout the Ohio Valley and the South. It was considerably warmer in the upper Mississippi Valley, but elsewhere temperature changes had not been of consequence, and in the far West pressure had risen considerably, but with light local rains in Montana, Idaho, and Utah. Frost warnings were ordered for the north Pacific States. The western

disturbance continued northeastward with about the same intensity, and on the morning of the 25th it was central over northern Lake Michigan, but, as pressure was still low for a considerable distance to the westward, there had been no strong winds. The rain area had extended through the Ohio Valley and the Lake region generally and locally into the Middle Atlantic States. There had also been substantial thundershowers in the west Gulf States. Temperatures were much higher over the eastern half of the country but were moderate elsewhere, with frosts in the interior of the north Pacific States. Owing to the strong pressure gradient to the eastward of the storm center, southwest storm warnings were ordered at 10 a. m. for Lake Ontario and extended on Lake Erie. However, they were not verified by subsequent occurrences, as the disturbance rapidly disintegrated during the night of the 25th, and on the morning of the 26th rains were falling in western New York, the Middle Atlantic States, and New England, with some snow over northern New England. By this time another disturbance had developed over the extreme West and was central over northwestern New Mexico, with rains continuing over Texas.

The northern disturbance moved off the southern New England coast and was followed by clearing weather, but the southwestern one moved eastward, and on the morning of the 27th it was central over western Oklahoma, with a secondary center over the middle Rio Grande Valley of Texas. Pressure was rising rapidly to the northward, with a marked crest over northern Saskatchewan, and at the same time temperatures had fallen considerably below the freezing point in North Dakota. Rains continued in Texas and extended northeastward into the upper Mississippi Valley. There were also rains in the North Pacific States, snows and rains in the central Rocky Mountain region, and rains in New York and New England, the latter from the northern low area that was just passing off the south coast. High temperatures prevailed in the upper Lake region and the Central valleys. Small craft warnings were ordered on the Texas coast, and on the east Gulf Coast from Pensacola to Carrabelle, and, as pressure was again rising in the North Pacific States, frost warnings were ordered for that section. Heavy to killing frosts occurred on the morning of the 28th as forecast. Warnings were also issued for the frosts in northern New Mexico that occurred on the morning of the 28th.

As special observations received during the 27th indicated the northeastward movement of the Oklahoma disturbance, small-craft warnings were ordered at 3 p. m. for western Lake Superior and, as the night observations indicated a still further development of the cold, high area to the northward, northeast storm warnings were ordered on Lake Superior from Duluth to Ashland. On the morning of the 28th the Oklahoma disturbance was over the upper Mississippi Valley, while the secondary one was near the mouth of the Rio Grande. Strong, cold, high pressure lay like a saddle over the northern disturbance, with distinct crests of about 30.40 inches over northern Saskatchewan and the territory immediately to the southward of Hudson Bay, and there had been also a decided fall in temperature to much below normal conditions through the Plains States and the Southwest, with low temperatures continuing in the Northwest and the Far West.

As conditions were now more marked, northeast storm warnings were ordered during the 28th for northern Lake Michigan, and during the evening of the 28th for the remainder of Lake Superior, while at the same time they were continued over western Lake Superior, warnings also containing information that snow was probable over Lake Superior. Warnings of heavy frosts or freezing temperatures were also issued for the Northwestern States as far south as Nebraska and northwestern Iowa, and they were also repeated for the North Pacific States. Snows and winds occurred as forecast on Lake Superior and northern Lake Michigan, and on the morning of the 29th the storm was central over eastern Lake Erie, with much diminished intensity, having turned to the eastward after reaching southern Lake Michigan. Snows and rains were falling generally from the Ohio Valley and the Lake region eastward, and thunderstorms also extended into the eastern Gulf States. Over the West and the extreme North pressure was high, with abnormally low temperatures that had extended by this time into the upper Lake region. Frost again occurred in the North Pacific States and light frosts as far south as southwestern Kansas. In the Atlantic States temperatures were high.

On the morning of the 30th high pressure prevailed throughout the country except along the Atlantic coast and in the extreme Southwest, but with generally cloudy weather and with local rains and snows east of the Rocky Mountains. The center of the high pressure was over Lake Superior (Port Arthur, Canada, 30.62 inches) and, as special observations indicated a rapid clearing of weather, frost warnings were issued for the lower Lake and southern upper Lake region, the upper Ohio Valley, and the Middle Atlantic States. On the morning of May 1 frosts occurred as far south as Virginia and Kentucky, the clearing weather having moved a little farther southward than had been anticipated. At the end of the month fair weather and high pressure prevailed generally, except in the extreme Southwest and the extreme Canadian Northwest, with low temperatures generally except in the Pacific States.

NORTHERN HEMISPHERE PRESSURE DISTRIBUTION.

The high pressure that had prevailed during most of the month of March over Alaska and the Aleutian Islands continued during the first two decades of April with some diminution in magnitude over the Aleutians and a moderate increase over western Alaska. After the 10th of April moderately low pressure prevailed over the southern and after April 20 over the northern and eastern sections, but with some recovery during the latter days of the month.

Over the Pacific States there was a rapid alternation of high and low pressures, but none were of decided character except the low area that prevailed on the California coast on the 21st and 22d. In the interior, as far east as the Missouri River and southward to Texas, high pressure predominated largely during the first decade of the month with a principal crest on the 7th over the Canadian Northwest. These conditions of high pressure were followed by a return to more normal conditions with the usual alternation of moderate high and low pressures, with the latter predominating somewhat, until the last few days of the month, when there was a return to somewhat above normal conditions. East of the Missouri River there were no special features connected with the pressure. There were only two quite well-marked disturbances over the upper Lakes and also one or two fairly strong high pressure areas, but nothing of particular consequence. Over the East and Southeast the storm movement was somewhat more active, but without any strong high-pressure areas following. There was strong storm development over the northeastern sections on the 2d and

3d, on the 13th, and again during the last two days of the month. The Middle and South Atlantic States did not exhibit any special changes, and, on the whole, above-normal pressures predominated slightly. Over the western Atlantic Ocean, as indicated by reports from Bermuda and Turks Island, moderately high pressure prevailed throughout the month, with a few minor exceptions. Over the eastern Atlantic, as indicated by reports from the Azores, similar conditions prevailed except during two days, and on the last day a pronounced disturbance prevailed. Over the British Islands and Iceland, after three or four days of normal conditions, abnormally low pressure prevailed, particularly over Iceland, until the 14th when there was a return to high pressure for the remainder of the month, except over Iceland where it remained low almost constantly until the last two days of the month. Over western continental Europe high pressure also prevailed generally, except for a few days during the first half of the month, and between the 15th and 28th high pressure was quite marked over Germany and France. Farther northward to the Arctic Circle pressure conditions did not differ much from the normal during the first decade of the month, but after that time pressure was abnormally low with an occasional reaction toward normal conditions. Over eastern Europe there were alternations of moderate high and low areas during the first two decades of the month, but during the third decade pressure was generally low with a marked minimum on the last day of the month over northern Russia. It should be remarked, however, that over southeastern Europe there was no low pressure of consequence, moderately high pressure prevailing generally. Over Siberia there was a general tendency toward low pressure with a decided fall on the 6th and 7th, and again on the 23d and 24th. There were no marked high areas after the fifth day of the month. The same general conditions that prevailed over Siberia also extended southward over eastern China and Japan.

Over the North Pacific Ocean, as indicated by reports from Honolulu, there was a continuance of the low pressure of the previous month that lasted until the 19th, with quite marked depressions on the 2d and 10th. After the 19th there was a return to slightly above normal conditions until the 28th, when pressure again fell to normal.

SECTION IV.—RIVERS AND FLOODS.

RIVERS AND FLOODS, APRIL, 1914.

By ALFRED J. HENRY, Professor of Meteorology, in charge River and Flood Division.

[Dated May 26, 1914.]

THE MISSISSIPPI BASIN.

As foreshadowed in the March Review, the annual spring rise in the Mississippi did not approach the dignity of a flood. Indeed, it would be difficult to point to any rise in the Mississippi below Cairo, during the present season and identify that particular rise as the annual spring rise of 1914. The lower part of the river—Cairo to the Passes—is controlled so completely by the Ohio that should there be no decided spring rise in that river none will occur in the Mississippi.

The lower portion of the Ohio only was in light flood for a period of about one week, in the early part of the month. This rise was due to rains which set in over the Ohio River and tributaries on March 26. The rise was most pronounced in the Evansville (Ind.) district, and it also extended down river as far as Shawneetown, Ill. The flood stage at Evansville, 35 feet, was passed on the 4th and the river crested at 38 feet on the 7th. It fell below the flood stage shortly after midnight of the 11th.

The small flood wave thus created was not augmented in the Mississippi—Cairo to the Passes—but there was enough water in it to make a technical flood at Arkansas City, Ark. (flood stage, 42 feet), where a crest stage of 43.2 feet was reached on the 28th. Thus ended the probability of a flood in the lower Mississippi during the spring of 1914.

Rivers tributary to the Ohio.—The Wabash River was at and above the flood stage at Lafayette, Ind., on the 8th and 9th, and at Terre Haute, Ind., from the 9th to the 14th; the crest stage at the latter being 17.1 feet, or 1.1 feet above the flood stage. While the lowlands along the river were inundated, no damage of consequence was sustained. In Ohio, owing to moderately heavy rains about the 7th the rivers became threatening, and at a few points rose to flood stage; but no serious damage resulted.

Western tributaries of the Mississippi.—The Missouri was low for the season. The Arkansas was not high at any time during the month, but relatively high stages were reached in the Red River and its tributaries between Shreveport, La., and Denison, Tex., as follows:

City.	Crest.	Date.	Flood stage.
	Feet.		*Feet.*
Arthur City, Tex	15.9	Apr. 2	27.0
White Cliffs, Ark	27.7	Apr. 2, 3	28.0
Fulton, Ark	31.3	Apr. 4	28.0
Shreveport, La	23.1	Apr. 10	29.0

The damage caused by this flood was confined mainly to machinery and equipment of oil wells near Shreveport. Loss to crops, owing to the time of year, was insignificant.

RIVERS OF TEXAS.

Heavy rains on the headwaters of the Trinity on April 22–28 and again on May 2, 3, and 4 caused a considerable flood in that river at Dallas, which later passed the flood stage, 25 feet, on the night of April 25–26, and reached a crest stage of 37.8 feet three days later. Much bottom land was overflowed and many bridges and culverts were washed out, thus seriously interrupting railroad traffic. The only other damaging overflow was in the Brazos at Waco. The crest of the flood in the Brazos occurred at Waco on the 28th, with a stage of 28 feet, 6 feet above flood stage. The Guadalupe, Neches, and Sabine were bank full in their lower portions at the close of the month. Further mention of these floods will appear in the May Review.

RIVERS OF GULF AND SOUTH ATLANTIC STATES.

Owing to almost continuous and fairly heavy rains over the Gulf States from March 25 to April 1 the rivers of Mississippi and Alabama exceeded flood stages at a number of places during the first week of April. The town of Jackson, Miss., was overflowed on March 28 and again on the 31st by the waters of Town Creek, a shallow creek that flows through the center of the town. Over 100 business houses were flooded. (A. S. Hall, river observer.) The Pearl River of Mississippi was in flood both at Jackson and Columbia, Miss.

The Tombigbee and Black Warrior Rivers of Alabama were both in flood at a number of points along their courses in the early part of April, due to the period of rains above mentioned. Heavy rains in the upper drainage areas of the Santee River system on April 14–15 caused moderate floods in the Catawba, Wateree, and Santee Rivers. The same period of heavy rains caused freshet stages in the Pedee at Cheraw, S. C.

NORTHERN RIVERS.

Two floods occurred in the Connecticut River, the first being in the nature of a moderate freshet but the second one caused a crest stage of 21.9 feet, 5.9 feet above flood stage at Hartford. Both floods were due to rainfall in connection with a short period of high temperature. The damage was not great.

The Hudson at Albany and Troy was at flood stage on April 9, due to heavy rains and a short period of high temperature. A second flood occurred at both places on the 21st concurrently with the flood in the Connecticut.

Flood loss, April, 1914, tangible property, bridges, roads, etc.

Red River	$10,000
Trinity River	75,000
Pearl River [1]	57,000
Santee River system	2,500
Hudson	51,000
Total	145,000

[1] Including city of Jackson, Miss.

SNOWFALL IN HIGH ALTITUDES, APRIL, 1914.

California.—There is a large amount of well-packed snow in the higher mountain regions, containing about 50 per cent water. The snowfall for April was confined to the higher levels and the fall was about normal.—*G. H. Willson, Local Forecaster.*

Nevada.—The greater portion of the snow on southeast, south, southwest, and west slopes has disappeared. On northwest, north, and northeast slopes drifts from 10 to 20 feet deep may be found at the higher elevations. Above 8,000 feet there has been but little run-off. Considerable snow fell during April in the mountains and at all levels in northern and eastern portions of the State during April.—*H. S. Cole, Section Director.*

New Mexico.—The snowfall of the month averaged 4.2 inches for the State as a whole. This is about an inch above the normal for the month and gives a seasonal fall of 30.2 inches, which is about 2 inches above the normal. The northern mountain areas were well favored with snow, the fall over the western slopes of the Sangre de Cristo Range being especially heavy. A fair depth (good for so late in the season) also occurred in the higher districts of Torrance, Lincoln, and eastern Otero Counties, while more or less snow fell over the entire eastern half of the State, reaching a depth of 4 to 6 inches over the higher plateau region of Colfax, Mora, and San Miguel Counties. Melting was active after the sharp cold period of the first decade, and streams were generally much swollen by the close of the second decade.—*C. E. Linney, Section Director.*

South Dakota.—The average snowfall in the Black Hills district was 8.1 inches, the monthly amounts ranging from a trace to 36.5 inches. The greatest monthly amount recorded was at Hardy Ranger Station, in the southwestern portion of Lawrence County, and near the Wyoming line. Much of the greater portion of the monthly amount at all stations occurred after the 15th and there was practically no snow remaining on the ground on that date. Much of the snow melted as it fell or soon after; the month closing with an average of only about 0.5 inch remaining on the ground in that region, mostly confined to Lawrence County. Rain and melting snow during the latter part of the month materially augmented the volume of water in the Black Hills streams, but there is no snow of consequence remaining in the gulches. The irrigation reservoirs appear to be well filled. The engineer in charge of the United States Irrigation Project at Bellefourche, S. Dak., advises that 108,000 acre-feet of water is in storage in the reservoir of that project, an increase of 14,000 acre-feet over that on hand at the close of March and probably more than will be used on the Bellefourche project during the season of 1914.

Washington.—There was less than the average snowfall and everywhere there was less than the average amount of snow remaining on the ground. No snow occurred below the 2,000-foot level, and at the higher stations the amounts did not exceed 15 inches.

The total snowfall of the season now ended was the least since the beginning of the official record, and is probably the least seasonal snowfall in the mountains of this section for many years.

Snowfalls at Laconia, Wash.

Years.	Total snow.
	Inches.
1913-14	400
1912-13	572
1911-12	437
1910-11	413
1909-10	548

The above records at Laconia in Snoqualmie Pass at an elevation of 3,150 feet show the deficiency as compared with previous years.—*G. N. Salisbury, Section Director.*

ANNOUNCEMENT.

RESUMPTION OF SEISMOLOGICAL WORK.

Authority having been granted by Congress for the Weather Bureau to conduct seismological work, to begin with July 1, 1914, this work will accordingly be resumed.

As but limited funds are available for inaugurating the work, it will consist at the beginning of a systematic collection of non-instrumental reports, to be rendered on post cards or other appropriate form, giving the essential features of such slight earthquakes as are likely to be felt in almost any part of the United States. Particular attention will be paid, however, to the Pacific coast and Rocky Mountain regions; the Mississippi Valley in the vicinity of Missouri; certain parts of New York State and New England, and possibly the region in the vicinity of Charleston, S. C.

It is believed that by the collection and study of numerous reports of this character it will be possible to locate sections of the United States where seismic motion on existing fault lines is taking place with some frequency and regularity. The location and mapping of these points of weakness are of great importance in the conduct of certain kinds of engineering work, especially those relating to great water-supply projects or similar engineering undertakings where it is necessary to provide against injuries resulting from possible earthquake motions.

The development of the work along instrumental lines, which will proceed as rapidly as funds permit, contemplates the establishment of a limited number of instrumentally-equipped stations that will serve to yield records not only of sensible seismic phenomena, but also of the great unfelt vibrations resulting from large distant earthquakes.

The seismological work will be under the supervision of Prof. William J. Humphreys.

C. F. MARVIN,
Chief of Bureau.

SECTION V.—BIBLIOGRAPHY.

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C. FITZHUGH TALMAN, Junior Professor, in charge of Library.

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NOTES FROM THE WEATHER BUREAU LIBRARY.

By C. FITZHUGH TALMAN, Junior Professor, in charge of Library.

NEW WAYS OF STUDYING CLIMATE.

There has recently been founded at Davos, the well-known altitude resort in the Swiss Alps, a private observatory that has set a new pace in the study and measurement of climate. This institution differs widely in its aims and equipment from every other observatory in the world, and an account of it should be of interest not only to the meteorologist and the climatologist but also to everyone who is concerned with any of the manifold applications of climatology, as the botanist, the zoologist, and the agriculturist. Especially, since the climate of Davos is renowned for its beneficial effects on consumptives, should the work of the new observatory interest the medical man.

At Davos, as at all other important health resorts, ordinary meteorological observations have been regularly made and their results have frequently been discussed from the medical point of view. A station of the federal meteorological service has existed at Davos since 1867, and is one of the best equipped in Switzerland. The observations are taken by officials of the Kurverein, and the results are posted daily outside the Kurverein building. Thus an instructive comparison may be made here between the methods of the old and the new climatology, as exemplified, respectively, in the official meteorological station and the newly founded private observatory.

The existence of the latter was made known to the world at large in the year 1911, when its owner, Dr. C. Dorno, published a voluminous account of his observations made during the three years 1908–1910.[1] Obliged for family

[1] C. Dorno, "Studie über Licht und Luft des Hochgebirges," Braunschweig, 1911.

reasons to live at Davos, Dr. Dorno set himself the task of studying the previously neglected factors in its climate. Ordinary meteorological measurements formed but a minor part of the program. His observations related to two principal subjects, viz (1) radiation, and (2) atmospheric electricity.

Measurements of the total solar radiation are no novelty. Formerly they were made with the now discredited black-bulb thermometer, and at present they are made at a comparatively small number of observatories with several forms of pyrheliometer. It is well known, however, that the various components of solar radiation—i. e., radiation of various wave-lengths—exercise quite different climatic effects, and, moreover, undergo different degrees of absorption in the earth's atmosphere. The most refined and detailed measurements in different parts of the spectrum are those made with the bolometer, but there are several less costly and elaborate instruments—none of them in general use by meteorologists—for studying particular regions of the spectrum. Dorno finds it convenient to measure separately (1) thermal radiation, (2) luminous radiation, (3) blue-violet and ultra-violet radiation. For (1) he uses a Michelson actinometer, checked by an Ångström pyrheliometer; for (2) Weber's photometer; and for (3) the Weber-Koenig photographic apparatus for the blue-violet, or photographically effective rays, and the Elster-Geitel zinc-globe photometer for the ultra-violet. The latter instrument depends upon the discharge by ultra-violet light of a negatively electrified body—the "Hallwachs effect." Finally Dorno has himself devised an ingenious instrument for making a continuous photographic record of the length of the ultra-violet spectrum, i. e., the value of the shortest wave-length that penetrates the atmosphere from the sun. This varies from day to day and from hour to hour.

It will be impossible within the limits of the present note to record all the interesting results attained through Dorno's novel and versatile observations, but we may pause here for a moment to mention a few things that he has found out, as a result of the measurements above mentioned, about the true inwardness of the famous Davos sunshine. This important therapeutic element varies greatly in quality with the season. The winter sun has great heat for the season, but very little ultra-violet radiation. The spring sun has the greatest heat, with slightly enhanced ultra-violet. The summer sun has great heat and the strongest ultra-violet. The autumn sun has great heat and but slightly diminished ultra-violet. Thus there is a very marked difference between spring and autumn at Davos as to the intensity of the ultra-violet radiation, a fact of much therapeutic importance. In commenting on Dorno's results Dr. Gockel has recently suggested that we have here an explanation of the so-called "glacier-burn," experienced by the invalids at Davos only in summer—it is probably due to the intense ultra-violet radiation. Dorno also finds that the heat of the sunshine at Davos varies quite regularly with the sun's angular altitude; that its luminosity varies somewhat with season and other conditions; that its photographic intensity (blue-violet) is still more influenced by atmospheric conditions, and bears comparatively little relation to the sun's altitude; and, lastly, that the ultra-violet radiation undergoes a hundredfold more variation than the heat, and, as stated above, varies greatly with the season; so that a single day in summer may give as much as a whole month in winter. The applications of such facts must be left to the biologist, the physiologist, the therapeutist; they can hardly fail to be of great value.

We can only briefly mention some of the other lines of investigation carried on at this unique observatory. Dorno's book on the subject is a mine of information and especially of suggestion, from which each reader will pick out the facts that bear upon his own particular sphere of interest.

As to radiation, the direct rays of the sun are only part of the problem. The combined radiation of sun and sky is measured at Davos, especially as to luminous and photographic intensity. In this connection several interesting facts have been brought to light; e. g., the comparatively small luminous but great photographic intensity of the diffuse blue light of the sky. Studies are also made of the color-composition of the light (red and green). Finally, the effects of different degrees of cloudiness are measured. All these observations are carried out with apparatus devised by Prof. Weber of Kiel. Nocturnal radiation from the earth is measured with A. K. Ångström's "tulip" apparatus.

The observations in atmospheric electricity include measurements of potential gradient, conductivity, the earth-air current (deduced from the two preceding), dissipation, and induced radioactivity, according to methods developed in very recent times, but presenting no novel features to persons familiar with contemporary (mainly German) literature on this subject. Benndorf electrometers are used, wherever appropriate, to secure continuous registration. Dorno draws from his observations various conclusions as to the relations of electric phenomena to the therapeutic features of the Davos climate—e. g., the relation between electric conductivity and the purity of the air; the stimulating effect of the earth-air current; and the probable physiological influence of the greatly increased conductivity observed during a foehn wind—for the details of which the reader must consult his work above cited.[2]

Several subsidiary lines of work that we have not space to mention are carried on at the observatory. A list of its instrumental equipment reads like the catalogue of a meteorological museum, including some forms of apparatus that are not familiar even by name to most meteorologists—such as Frankenhäuser's homœotherm, for measuring the cooling effect of the atmosphere; Wolpert's carbacidometer, for determining the amount of carbon dioxide; and the Engler-Sieveking fontactoscope, for measuring the radioactivity of springs.

From the *Zeitschrift für Balneologie* for April 15, 1914, page 54, we learn that institutions more or less analogous to Dorno's observatory are to be established under official auspices at Kolberg, a seashore resort on the Baltic, and at Oberhof in the Thuringian Forest, which is intermediate in altitude between Davos and Kolberg. This is part of a program which contemplates elaborate physical, meteorological, physiological, and psychological investigations of climate at a large number of German health resorts, to be carried out under the direction of Drs. Hellmann, Zuntz, and His.

In all this we have a signal recognition of the inadequacy of the existing data of meteorology for many, if not most, of the purposes of medical climatology.

"STRAYS" IN RADIOTELEGRAPHY.

A condition of the ether characterized by the occurrence of erratic signals in wireless telegraphic receivers due to natural electric waves is perhaps best known to American operators under the name of "static." These

[2] The medical reader should also consult Dorno's "Vorschläge zum systematischen Studium des Licht- und Luftklimas," in Zeitschrift für Balneologie, May 15 and June 1, 1912.

waves, or their effects, have been variously known as "strays," "statics," "atmospherics," and "X's." In France they are often called "parasites."

This subject is of meteorological interest for the reason, among others, that "strays" are produced by lightning discharges, and furnish a means of observing the occurrence and movements of distant thunderstorms. Thus we have several forms of thunderstorm-recorders, some of which ("ceraunographs") inscribe an automatic record, while others ("ceraunophones") are fitted with telephone receivers for producing audible signals. Most of the existing literature on thunderstorm-recorders conveys the impression that all of these natural signals are due to lightning, either near or distant, but the trend of opinion among special students of this subject is now toward the belief that "strays" are of various origin, in part extraterrestrial.

Perhaps the most active student of these phenomena is Dr. W. Eccles who, in collaboration with H. M. Airey, published an important paper on the subject, "Note on the Electrical Waves Occurring in Nature," in the proceedings of the Royal Society, series A, volume 85, 1911, pages 148–150. Recently the British association has appointed a committee, of which Dr. Eccles is secretary, to investigate these and other obscure phenomena connected with radiotelegraphy.

In the Yearbook of Wireless Telegraphy and Telephony (London) for 1914, Dr. Eccles publishes an account of the investigations undertaken by this committee and specimens of the observation forms which have been distributed to wireless operators throughout the world who are cooperating in the work of the committee. In the United States observations are being made by the Signal Corps of the Army and also at certain universities. The following quotation from Dr. Eccles's paper represents the existing state of knowledge in regard to "strays":

These natural electric waves cause erratic and troublesome noises in the telephone receivers of a wireless telegraph station or cause erratic and confusing marks on the tape of a coherer and inker set. They are only too familiar to everybody who has worn the phones of a wireless operator for even a brief interval. For brevity they were christened "strays" or "X's" in the years 1897, 1898, and 1899 in England and were later given the name "atmospherics" in the United States. Another and more recent Americanism is "static." The best name appears to the writer to be "strays," for the word exactly describes their vagrant nature and does not commit one to any opinion as regards their origin. The much-used word "atmospheric" suggests that they are wholly due to discharges of atmospheric electricity, and no doubt the word "static" is intended to convey the same idea. "Atmospherics" is, besides, a dreadfully long word to have to write often. From the point of view of brevity "X's" is the best term, but it is not quite accurate. On the whole, from the point of view of priority, of accuracy, of freedom from ambiguity, and of the absence of bias—not to mention reasonable brevity—the writer favors the term "stray" as the best short term for a natural electric wave train, with "X" as a good variant. The latter term may be held to include, as "stray" does not, the noises caused by discharges of local atmospheric electricity down the antenna.

Now, to the scientific mind, the chief claim of strays to promptness of attention is that nobody knows completely what they are or whence they come. The study of strays was begun by Popoff shortly before the rise of practical wireless telegraphy. In 1895 Popoff made use of a long vertical conductor (such as a lightning rod) in combination with a coherer in order to follow the motions of lightning storms across the country. A filings coherer was used, and was automatically tapped back after registering the effect of each lightning stroke. In 1898 Boggio Lera improved on Popoff's apparatus as regards sensitiveness and arranged that feeble and strong disturbances should be recorded separately. His experiments with this apparatus in 1899 showed that the approach of electrical storms was heralded by frequent operation of the apparatus several hours in advance of their arrival in the locality of the observing station and showed also that every visible flash operated the apparatus infallibly. These results were confirmed in 1900 by Tommasina, using his carbon autodecoherer. In 1901 Fenyi showed that the thunderstorms occurring within 100 kilometers of his station at Kalocsa, Hungary, were all recorded by his coherers. Finally, Turpain, in 1903, made a long series of observations which proved the possibility of utilizing radiotelegraphic apparatus in the forecasting of thunder weather for hours and even days in advance.

But even when there is no thunder weather recorded over the whole continent of Europe and the adjacent seas, X's may be received almost perpetually by a receiving antenna adjusted to a great wave length. This is quite a distinct matter from the X's due to local atmospheric electricity utilizing the antenna as a lightning rod and different again from the hum or sizzle or fizz caused by a white squall at sea or by glow discharge to high peaks. These perpetual strays are characterized by the fact that they are heavier and more frequent, in general, the longer the wave to which the receiving antenna is adjusted, so far as has been tried up to the present. It is natural but it is not scientific to jump to the conclusion that these strays are all due to lightning strokes occurring probably at great distances somewhere on the earth's surface, or possibly in the free atmosphere between one bank of ionized air and another. This, however, ignores the possibility that the source of the strays may be far outside the earth. There is nothing unreasonable in supposing that the sun, let us say, may send us occasional electric waves. For example, in the colossal movements of matter associated with the formation of a solar prominence—movements that appear to take place with enormous velocities—electric discharges may be brought about of magnitude far transcending anything that can happen on the earth. These would give rise to electric waves which might reach the earth in perceptible intensity and constitute a proportion of our strays. On the other hand, we must not forget that we on the earth's surface may be protected by our ionized atmosphere from these extraterrestrial waves. It is just such problems as these that the British Association Committee has set itself to inquire into.

The writer further explains that three kinds of strays are commonly heard during the telephonic reception of signals. One is a more or less prolonged rattling or grinding noise ("grinders"); another kind consists of sharp isolated knocks ("clicks"); and a third consists of a buzzing or frying noise ("hum" or "sizzle"), and is often heard during a white squall. A period of unusually loud or numerous strays is known as an "X" storm. In the scheme of coöperative observations, since the character and number of strays received differ greatly with the wave length to which the receiving apparatus is adjusted, observations are requested especially on two wave lengths, viz, about 600 meters and about 2,000 meters, while observers possessing the necessary apparatus are requested to add records made with about 5,000 meters wave length. Observations are especially desired at 11 a. m. and 11 p. m., Greenwich mean time, as simultaneous observations in various parts of the world will indicate whether particular cases of strays may be of world-wide or widespread occurrence, pointing to a cosmical origin. Observations are also desired about the transition time between daylight and darkness. The forms furnished to observers call for information regarding various concomitant meteorological phenomena, such as the kind of clouds, wind, barometer, temperature, etc.

SECTION VI.—WEATHER AND DATA FOR THE MONTH.

THE WEATHER OF THE MONTH.

By P. C. DAY, Climatologist and Chief of Division.

Pressure.—The distribution of the mean atmospheric pressure over the United States and Canada, and the prevailing directions of the winds, are graphically shown on Chart VII, while the average values for the month at the several stations, with the departures from the normal, are shown in Tables I and III.

For the month as a whole barometric pressure was above the normal over practically all districts, only the Florida Peninsula, the central and southern Plateau region, and along the central and south Pacific coast showing values near the normal or slightly below. The greatest positive departures occurred in the central and upper Missouri Valley.

The month opened with relatively low pressure prevailing over the eastern districts, while barometric readings were correspondingly high over the Rocky Mountain and Plains regions. A low-pressure area moved from Oregon to Texas on the 9–11th and during the next few days an extensive area of high pressure prevailed over the central valleys and to the eastward. About the 16th a barometric depression of considerable magnitude developed over the Plains region, and moving thence northeastward during the next few days disappeared off the New England coast about the 21st. From the 22d to 24th pressure was again high over eastern districts, but the remainder of the month was characterized by unsettled barometric conditions and generally showery weather over the greater portion of the country.

The distribution of the highs and lows was favorable for the occurrence of southerly winds as prevailing direction over the southern portion of the central and eastern districts and from a northerly or westerly direction over the northern portion, while the prevailing directions were variable from the Rocky Mountains westward.

Temperature.—At the beginning of the month moderately warm weather obtained over nearly all portions of the country, but after the first few days temperatures fell to below the seasonal average over the eastern districts, and by the 9th they had fallen to the freezing point as far south as the interior of the Gulf States and were as low as 20° in the Panhandle of Texas. Still lower temperatures followed and by the 11th they were from 10° to 15° below freezing generally in the middle Plains region and the Missouri Valley, and by the 13th they were below zero at exposed points in New England.

About the 15th warmer weather set in and temperatures became high for the season of the year to westward of the Rocky Mountains and generally above normal in most districts to the eastward. There was a tendency to colder weather in the latter districts about the beginning of the third decade, especially in the Lake region, Ohio Valley, and Appalachian Mountain districts, the temperature falling to the freezing point as far south as central Indiana and at points in the southern Appalachian Mountain region, the minimum temperature on the morning of the 21st was near the lowest ever recorded in that region during the third decade of April. At the same time temperatures were rising in the western districts, and by the 25th they were above normal over nearly all portions of the country east of the Rocky Mountains, except along the north Atlantic coast. During the last few days of the month cool weather prevailed over northern districts, while in the central valleys and Southern States temperatures were moderately high for the season.

For the month, as a whole, the temperature averaged above the normal in all districts to westward of the Rocky Mountains and also in the Missouri, central Mississippi, and Ohio Valleys, as well as in the Middle and South Atlantic and east Gulf States, although the departures were not pronounced. The greatest plus departures occurred along the Pacific and South Atlantic coasts. In the lower Mississippi Valley, the west Gulf and southern Plains States the mean was somewhat below the normal, as it also was in the extreme upper Mississippi Valley, the Lake region and the North Atlantic States.

Precipitation.—The generally rainy condition prevailing during the latter part of March over the eastern districts continued during the first few days of April, and about the 6–9th a storm moved from western Texas northeastward to the New England coast, accompanied by more or less precipitation from the middle and southern Plains region eastward. Again, about the 11–12th moderate rains were quite general from Texas eastward and northeastward to the Atlantic coast, turning into snow in the upper Lake region. Over the Rocky Mountain region and to westward precipitation during the first decade was light and local, except for some moderately heavy falls near the end in northern California and portions of Oregon and Washington.

About the 14–16th considerable rain occurred over the Gulf and Atlantic Coast States, and as this storm moved to sea another was developing in the Great Plains region, which caused precipitation over much of the Plains country from Texas to the Dakotas and to the eastward. About the 22d rains set in over Texas and other portions of the Southwest, and during the next few days precipitation occurred over much of the Plains region, upper Mississippi Valley and portions of the mountain and plateau districts to the westward. During the remainder of the month showery, unsettled weather prevailed over most of the country.

For the month, as a whole, precipitation was quite heavy, ranging from 6 to 8 inches in portions of Texas and the lower Mississippi Valley, while amounts ranging from 4 to 6 inches occurred in the upper Ohio Valley, Pennsylvania, New York, and New England. Generous amounts

were received in the upper Mississippi Valley, and also quite generally from the Rocky Mountains westward to the Pacific the amounts were above normal, except in California, where they were mostly below the average. Precipitation was below normal in the lower Ohio, middle Mississippi, and Missouri Valleys, as well as in the central Plains States, and it was light and less than the average for the period in most of the eastern Gulf and South Atlantic States, except the Florida Peninsula, where more than the normal amount was received.

Snowfall.—Considerable snow fell during the month in New York and northern New England, the amounts ranging as high as 17 inches at points in New York and 25 inches in northern Maine. From 4 to 5 inches occurred in the lower Lake region, while from 16 to 18 inches were received in upper Michigan, and amounts ranging from 1 to 4 inches were the rule over the northern tier of States to the westward. At the higher elevations of the West considerable snow appears to have fallen, especially in the central portions, with recorded amounts ranging as high as 35 inches in southwestern South Dakota and Colorado.

GENERAL SUMMARY.

During the first half of the month the weather was unseasonably cold over practically all portions of the country from the Rocky Mountains eastward, and as a result the season's progress was materially delayed, but over the far Western districts these conditions were reversed and the season was well advanced. The latter half of the month was more favorable as to warmth over eastern districts, with temperature quite generally above the normal, but at the close the season, as a rule, was late and vegetation retarded.

Throughout the principal corn and winter wheat growing States conditions were favorable for wheat, especially in the western sections, where beneficial rains afforded ample moisture, as was also the case in the spring wheat States. Over the eastern portion of the cotton belt conditions were favorable for much outdoor work, but in portions of the western belt heavy rains greatly interfered with farming operations.

In Alaska temperatures during the month were frequently higher than usual at points from which reports have been received to date, and the mean was quite generally from 2° to 6° above normal. Precipitation was near the normal amount at most points, the totals along the south coast being somewhat above normal, but with considerable minus departures along the coast of the Gulf of Alaska.

Average accumulated departures for April, 1914.

Districts.	Temperature.			Precipitation.			Cloudiness.		Relative humidity.	
	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1.	General mean for the current month.	Departure for the current month.	Accumulated departure since Jan. 1	General mean for the current month.	Departure from the normal.	General mean for the current month.	Departure from the normal.
	°F.	°F.	°F.	Inches	Inches.	Inches.			P. ct.	P. ct.
New England	41.4	−2.1	− 7.9	4.25	+1.20	+0.20	6.0	+0.5	75	+ 2
Middle Atlantic	50.0	−0.5	− 4.8	3.32	+0.30	−0.30	5.8	+0.6	69	+ 2
South Atlantic	62.9	+1.6	− 1.7	2.60	−0.80	−3.10	4.9	+0.3	72	0
Florida Peninsula	73.8	+1.0	− 4.4	3.23	+1.30	+0.10	4.6	+0.8	77	+ 3
East Gulf	65.3	+0.7	− 3.3	2.92	−1.20	−1.60	5.1	+0.2	69	− 1
West Gulf	64.3	−1.4	− 0.3	4.65	+1.20	−1.00	5.8	+0.7	73	+ 1
Ohio Valley and Tennessee	54.5	−0.2	− 3.6	3.62	0.00	−3.10	6.3	+1.0	68	+ 3
Lower Lakes	43.4	−1.7	− 7.0	3.71	+1.40	+1.00	6.5	+0.8	74	+ 4
Upper Lakes	39.3	−1.5	− 2.3	3.03	+0.70	−0.30	6.1	+0.6	74	+ 1
North Dakota	40.9	+0.2	+ 9.7	1.38	−0.50	−0.70	5.9	+0.6	69	+ 1
Upper Mississippi Valley	50.5	0.0	+ 4.5	2.40	−0.60	−2.00	6.3	+1.1	68	0
Missouri Valley	51.0	+0.5	+ 9.6	2.30	−0.80	−1.10	5.7	+0.1	65	0
Northern slope	44.0	+1.2	+13.1	1.73	−0.10	−0.80	6.5	+1.4	66	+ 8
Middle slope	53.0	−0.7	+ 9.7	2.30	0.00	−1.00	5.4	+0.8	66	+ 9
Southern slope	61.5	−0.9	+ 7.3	2.33	+0.40	−1.90	4.6	−0.1	58	+ 3
Southern Plateau	58.4	+0.5	+ 5.1	0.29	−0.10	−0.60	3.3	+0.5	42	+12
Middle Plateau	49.6	−1.1	+ 8.1	1.32	+0.20	+0.40	5.7	+1.2	54	+ 9
Northern Plateau	50.4	+1.4	+15.2	1.64	+0.30	−0.40	6.4	+1.2	59	+ 2
North Pacific	50.4	+2.1	+12.0	3.47	+0.10	+1.60	6.2	0.0	81	−10
Middle Pacific	55.6	+2.0	+ 9.4	1.56	−0.50	0.00	4.6	+0.2	71	− 1
South Pacific	60.8	+2.8	+14.6	0.65	−0.40	+4.20	4.4	+0.4	69	+ 1

Maximum wind velocities during April, 1914.

Stations.	Date.	Velocity.	Direction.	Stations.	Date.	Velocity.	Direction.
		Mi/hr				Mi/hr	
Block Island, R. I.	12	58	nw.	New York, N. Y.	20	50	nw.
Do	15	58	ne.	Do	22	68	nw.
Buffalo, N. Y	9	58	w.	Do	23	54	nw.
Do	12	54	w.	North Head, Wash.	4	62	se.
Do	18	50	sw.	Do	13	50	se.
Do	19	54	sw.	Do	14	56	s.
Canton, N. Y	12	56	sw.	Pierre, S. Dak	18	52	nw.
Cheyenne, Wyo	17	50	n.	Point Reyes Light, Cal	15	65	nw.
Do	23	60	w.	Do	16	64	nw.
Del Rio, Tex	25	52	sw.	Do	19	53	nw.
Devils Lake, N. Dak.	18	52	n.	Do	20	68	nw.
Duluth, Minn	28	51	ne.	Do	24	59	nw.
El Paso, Tex	16	50	sw.	Do	25	68	nw.
Fort Smith, Ark	24	50	sw.	Do	27	54	nw.
Lincoln, Nebr	19	55	nw.	Do	28	82	nw.
Louisville, Ky	18	58	s.	Pittsburgh, Pa	19	61	sw.
Mount Tamalpais, Cal	9	50	sw.	Providence, R. I	12	67	nw.
Do	15	64	nw.	Do	22	50	nw.
Do	16	68	nw.	Pueblo, Col	16	50	w.
Do	25	88	nw.	Do	23	50	nw.
Do	26	84	nw.	St. Louis, Mo	18	58	sw.
Do	27	62	nw.	Seattle, Wash	26	55	sw.
Do	28	58	nw.	Sioux City, Iowa	10	52	nw.
Do	29	52	n.	Do	19	52	nw.
Mount Weather, Va.	1	50	w.	Tatoosh Island, Wash	13	50	s.
Do	2	58	nw.	Do	14	54	s.
Do	8	68	nw.	Do	19	50	s.
Do	9	61	nw.	Toledo, Ohio	18	51	sw.
Do	20	52	nw.	Do	19	52	sw.
Do	21	64	nw.	Trenton, N. J	2	50	w.
Nashville, Tenn	14	50	ne.	Wichita, Kans	18	52	nw.
New York, N. Y	2	56	nw.				
Do	12	62	nw.				

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures with dates of occurrence; the stations reporting the greatest and least total precipitation, and other data, as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Temperature and precipitation by sections, April, 1914.

Section.	Temperature (°F.). Section average.	Departure from the normal.	Monthly extremes. Station.	Highest.	Date.	Station.	Lowest.	Date.	Precipitation (inches and hundredths). Section average.	Departure from the normal.	Greatest monthly. Station.	Amount.	Least monthly. Station.	Amount.
Alabama	63.8	+0.8	3 stations	91	17†	Cordova	25	10	3.84	−0.15	Talladega	6.40	Alaga	0.36
Arizona	61.0	+1.7	Maricopa	103	20	Alpine	16	18	0.20	−0.29	Whitehills	1.38	29 stations	0.00
Arkansas	61.0	0.0	Centerpoint	94	16	Dutton	19	9	4.57	+0.15	Hot Springs	11.29	Bentonville	1.99
California	56.6	−0.4	2 stations	105	15†	Summit	15	28	2.14	+0.35	Crescent City	9.85	6 stations	0.00
Colorado	44.3	+0.8	Lamar	95	21	Fraser	−5	11	2.45	+0.77	Monument	5.80	Manassa	0.54
Florida	71.1	+1.6	Wausau	98	26	Molino	32	10	2.42	−0.49	Fort Lauderdale	10.51	Live Oak	0.13
Georgia	64.9	+1.7	2 stations	97	28†	Ramhurst	27	10	2.70	−0.85	Tallapoosa	6.86	Bainbridge	0.46
Hawaii (for March)	68.2		Mahukona	89	24	Volcano House	45	11	7.53		Waiakamoi	23.12	West Lawai	2.39
Idaho	47.4	+1.3	Guffey	84	19	Pierson	−2	7	1.73	+0.36	Castle Creek	4.69	Bonners Ferry	T.
Illinois	52.7	+0.7	Quincy	90	26	Dakota	15	8	2.22	−1.18	Decatur	3.85	Walnut	0.65
Indiana	51.9	+0.1	Shoals	95	22	Collegeville	13	9	3.16	−0.20	Mauzy	4.98	Whiting	0.77
Iowa	48.6	−0.1	4 stations	88	16†	Lake Park	11	8	2.52	−0.34	Jefferson	5.03	Centerville	0.37
Kansas	57.4	+0.2	Farnsworth	99	21	Leoti	9	8	1.76	−0.79	Columbus	4.03	Hutchinson	0.10
Kentucky	55.7	−0.2	Beattyville	91	28	Beattyville	13	10	3.62	−0.45	Middlesboro	6.23	Williamstown	1.83
Louisiana	66.8	−0.6	Laark	99	16†	7 stations	32	9†	6.10	+1.80	Merryville	19.42	Paradis	2.55
Maryland and Del.	51.6	−0.5	Cumberland	89	18	Deer Park	15	6	3.82	+0.47	State Sanatorium	6.48	Solomons	1.87
Michigan	41.4	−0.9	Midland	89	18	Watersmeet	−5	8	2.92	+0.65	Whitefish Point	8.03	Port Austin	0.29
Minnesota	41.2	−1.5	Tracy	91	17	2 stations	2	5†	2.41	−0.47	Caledonia	4.66	Roseau	0.08
Mississippi	64.0	−0.4	Tchula	91	27	.....do	27	10	4.67	+0.17	McNeill	8.67	Hernando	2.64
Missouri	55.2	+0.1	Steffenville	91	26	Goodland	18	9	3.14	−0.74	Birchtree	7.58	Caruthersville	0.81
Montana	43.6	+2.0	Busby	85	15	2 stations	2	1†	1.13	−0.01	Flathead Creek	3.23	Chester	0.00
Nebraska	49.5	+0.4	2 stations	95	9†	Hillside	1	8	2.47	+0.07	Lodgepole	5.94	Nelson	0.63
Nevada	49.2	+0.3	Las Vegas	102	19	Geyser	5	3	1.23	+0.32	Eureka	3.57	Battle Mountain	T.
New England	40.8	−2.3	2 stations	88	19†	2 stations	−3	4†	4.66	+1.72	Benton, N. H.	11.18	Houlton, Me.	1.27
New Jersey	48.4	−0.7	Moorestown	89	19	Culvers Lake	15	4	3.67	+0.18	Charlotteburg	4.78	Lambertville	2.35
New Mexico	51.9	+0.4	2 stations	93	15†	Elizabethtown	7	8	1.53	+0.31	Clayton	7.04	15 stations	0.00
New York	41.4	−2.5	3 stations	86	19	Lake Placid Club	−1	4	4.60	+1.75	Greenfield Center	7.75	New York	2.67
North Carolina	58.5	+1.2	Montrose	97	29	Banner's Elk	17	10	3.68	−0.14	Highlands	7.53	Montrose	1.50
North Dakota	40.9	−0.5	Turtle Lake	84	26	Dunseith	2	7	1.66	+0.39	Power	4.10	2 stations	0.20
Ohio	50.1	+0.4	2 stations	91	28	Columbiana	12	9	4.01	+1.08	Hudson	6.83	Circleville	2.42
Oklahoma	59.4	−0.6	Frederick	97	16	Hooker	14	8	2.54	−0.52	Idabel	6.62	Hurley	0.80
Oregon	50.0	+1.6	Grants Pass	84	18	Crescent	12	28	2.71	+0.44	Waldo Lake	10.02	Bear Valley	0.33
Pennsylvania	47.3	−0.9	2 stations	93	18†	Pocono Pines	5	6	4.66	+1.47	Somerset	7.50	Lloyd	1.90
Porto Rico	75.2	0.0	.....do	93	11†	Maricao	52	11	4.41	−0.53	Inabon Falls	12.25	Isidora	0.24
South Carolina	63.7	−1.4	.....do	98	26	2 stations	30	10	2.86	−0.01	Clemson College	5.58	Winnsboro	0.65
South Dakota	45.6	−0.1	La Delle	90	17	.....do	2	8	2.69	+0.81	Dumont	6.14	Pollock	0.61
Tennessee	59.0	+0.9	Johnson City	94	28	.....do	18	10	4.11	−0.40	London	7.45	Byrdstown	2.29
Texas	64.8	−1.4	Seymour	101	16	Claytonville	18	9	4.28	+1.45	Angleton	15.16	Barstow	0.00
Utah	49.1	+1.3	St. George	91	20	Cisco	14	20	1.94	+0.44	Farmington	4.80	Thompsons	T.
Virginia	54.3	+0.5	Petersburg	95	29	Burkes Garden	14	10	2.61	−0.79	Winchester	5.04	Ashland	1.03
Washington	50.4	+2.1	2 stations	85	11	Antoine	16	1	2.49	+0.40	Forks	8.73	Eltopia	0.00
West Virginia	52.1	+0.7	Spencer	93	28	3 stations	16	6†	4.63	+0.83	Pickens	10.05	Bluefield	1.29
Wisconsin	42.1	−1.4	Muscoda	84	26	Vudosare	−4	6	2.82	−0.09	Glen Flora	5.04	Beloit	1.10
Wyoming	40.2	+0.4	Wheatland	84	15	2 stations	−8	1†	2.37	+0.96	Dome Lake	6.90	Daniel	0.20

† Other dates also.

DESCRIPTION OF TABLES AND CHARTS.

Table I gives the data ordinarily needed for climatological studies for about 158 Weather Bureau stations making simultaneous observations at 8 a. m. and 8 p. m., seventy-fifth meridian time daily, and for about 41 others making only one observation. The altitudes of the instruments above ground are also given.

Table II gives a record of precipitation the intensity of which at some period of the storm's continuance equaled or exceeded the following rates:

Duration (minutes)	5	10	15	20	25	30	35	40	45	50	60
Rates per hour (inches)	3.00	1.80	1.40	1.20	1.08	1.00	0.94	0.90	0.87	0.84	0.80

In cases where no storm of sufficient intensity to entitle it to a place in the full table has occurred, the greatest precipitation of any single storm has been given, also the greatest hourly fall during that storm.

Table III gives, for about 30 stations of the Canadian Meteorological Service, the means of pressure and temperature, total precipitation and depth of snowfall, and the respective departures from normal values, except in the case of snowfall.

Chart I.—Hydrographs for several of the principal rivers of the United States.

Chart II.—Tracks of centers of high areas; and Chart III.—Tracks of centers of low areas. The roman numerals show the chronological order of the centers. The figures within the circles show the days of the month; the letters *a* and *p* indicate, respectively, the observations at 8 a. m. and 8 p. m., seventy-fifth meridian time. Within each circle is also given (Chart II) the last three figures of the highest barometric reading and (Chart III) the lowest reading reported at or near the center at that time, and in both cases as reduced to sea level and standard gravity.

Chart IV.—Total precipitation. The scale of shades showing the depth is given on the chart. Where the monthly amounts are too small to justify shading, and over sections of the country where stations are too widely separated or the topography is too diversified to warrant reasonable accuracy in shading, the actual depths are given for a limited number of representative stations. Amounts less than 0.005 inch are indicated by the letter T, and no precipitation by 0.

Chart V.—Percentage of clear sky between sunrise and sunset. The average cloudiness at each Weather Bureau station is determined by numerous personal observations between sunrise and sunset. The difference between the observed cloudiness and 100 is assumed to represent the percentage of clear sky, and the values thus obtained are

the basis of this chart. The chart does not relate to the nighttime.

Chart VI.—Isobars and isotherms at sea level and prevailing wind directions. The pressures have been reduced to sea level and standard gravity by the method described by Prof. Frank H. Bigelow on pages 13–16 of the REVIEW for January, 1902. The pressures have also been reduced to the mean of the 24 hours by the application of a suitable correction to the mean of the 8 a. m. and 8 p. m. readings at stations taking two observations daily, and to the 8 a. m. or the 8 p. m. observations, respectively, at stations taking but a single observation. The diurnal corrections so applied will be found in the Annual Report of the Chief of the Weather Bureau, 1900–1901, volume 2, Table 27, pages 140–164.

The isotherms on the sea-level plane have been constructed by means of the data summarized in chapter 8 of volume 2 of the annual report just mentioned. The correction $t_0 - t$, or temperature on the sea-level plane minus the station temperature as given by Table 48 of that report, is added to the observed surface temperature to obtain the adopted sea-level temperature.

The prevailing wind directions are determined from hourly observations at the great majority of the stations; a few stations having no self-recording wind direction apparatus determine the prevailing direction from the daily or twice-daily observations only.

Chart VII.—Total snowfall. This is based on the reports from regular and cooperative observers and shows the depth in inches and tenths of the snowfall during the month. In general, the depth is shown by lines inclosing areas of equal snowfall, but in special cases figures are also given.

Chart VIII.—Depth of snow on ground at end of the month, expressed in inches and tenths.

Charts VII and VIII are published only when the general snow cover is sufficiently extensive to justify their preparation.

TABLE I.—*Climatological data for United States Weather Bureau stations, April, 1914.*

Districts and stations.	Elevation of instruments. Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Pressure in inches. Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Temperature of the air, in degrees Fahrenheit. Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches. Total.	Departure from normal.	Days with 0.01 or more.	Wind. Total movement, miles.	Prevailing direction.	Maximum velocity. Miles per hour.	Direction.	Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
New England.							**41.4**	**− 2.1**										**75**	**4.25**	**+ 1.2**										**6.0**		
Eastport	76	67	85	29.91	30.00	+ .07	35.6	− 2.7	64	19	43	16	3	28	48	33	29	78	3.93	+ 1.0	12	9,117	s.	44	ne.	2	7	14	9	6.0	11.5	
Greenville	1,070	6		28.82	30.01		31.6		72	19	42	− 3	13	21	34				4.51		11		se.								20.9	
Portland, Me	103	82	117	29.90	30.03	+ .07	39.8	− 3.2	77	19	47	22	4	32	30	35	29	69	4.42	+ 1.3	13	8,167	n.	40	nw.	12	11	3	16	6.1	2.5	
Concord	288	70	79	29.71	30.03	+ .04	40.4	− 3.4	82	19	50	18	14	31	41				3.87	+ 1.1	14	5,385	nw.	34	sw.	11	11	8	11	5.5	2.0	
Burlington	404	11	48	29.58	30.03	+ .04	38.2	− 0.3	80	19	47	16	13	30	31				4.27	+ 2.4	12	8,635	n.	46	nw.	12	4	11	15	6.9	5.5	
Northfield	876	12	60	29.07	30.04	+ .05	35.4	− 4.8	78	19	45	10	6	25	42	33	29	79	5.05	+ 3.0	15	6,147	s.	36	sw.	11	5	10	15	7.0	12.0	
Boston	125	115	188	29.88	30.02	+ .05	45.3	0.0	87	19	54	27	4	37	31	40	35	73	5.87	+ 2.3	12	8,622	nw.	47	w.	12	12	5	13	5.4	2.0	
Nantucket	12	14	90	30.00	30.01	+ .04	42.6	− 1.6	60	8	49	29	4	37	20	40	36	82	3.30	+ 0.7	13	13,089	sw.	47	e.	27	12	10	8	5.6	T.	
Block Island	26	11	46	29.98	30.02	+ .04	42.0	− 1.8	55	18	47	28	4	37	17	40	38	85	3.77	+ 0.2	16	13,541	sw.	58	nw.	12	13	1	16	5.9	T.	
Narragansett		9					42.6	− 2.0	60	17	50	23	4	35	27				4.81		16		sw.				13	4	13		T.	
Providence	160	215	251	29.84	30.02	+ .04	44.5	− 2.1	80	19	54	25	4	35	34	39	33	67	3.94	+ 0.2	14	10,839	nw.	67	nw.	12	12	4	14	5.5	T.	
Hartford	159	122	140	29.84	30.02	+ .03	44.7	− 2.0	82	19	53	26	4	36	31	39	33	68	3.84	+ 0.3	17	6,582	nw	37	s.	11	9	7	14	6.3	T.	
New Haven	106	117	155	29.91	30.02	+ .03	45.6	− 0.8	72	19	54	25	4	37	27	41	37	76	3.90	+ 0.3	13	7,976	nw.	39	sw.	2	9	8	13	6.0	T.	
Middle Atlantic States.							**50.0**	**− 0.5**										**69**	**3.32**	**+ 0.3**										**5.8**		
Albany	97	102	115	29.92	30.03	+ .03	43.8	− 2.0	85	19	53	25	6	35	35	38	33	72	5.78	+ 3.4	17	6,453	s.	37	s.	11	9	9	12	5.9	1.8	
Binghamton	871	10	69	29.08	30.02	.00	43.2	− 1.2	81	19	52	23	4	34	42				5.70	+ 3.4	17	3,979	nw.	27	nw.	12	3	12	15	7.2	3.9	
New York	314	414	454	29.68	30.03	+ .03	46.6	− 1.5	78	19	54	26	4	39	25	41	34	64	2.67	− 0.6	12	13,957	nw.	68	nw.	22	7	7	16	6.6	T.	
Harrisburg	374	94	104	29.65	30.05	+ .03	49.5	− 1.2	80	19	59	28	4	40	34	42	35	62	4.52	+ 2.0	12	5,846	nw.	36	sw.	19	6	13	11	6.4	T.	
Philadelphia	117	123	184	29.92	30.05	+ .04	51.0	+ 0.2	81	19	60	30	4	42	32	45	40	71	3.43	+ 0.5	8	8,574	nw.	35	ne.	15	8	8	14	6.0		
Reading	325	81	98	29.69	30.04		49.1		83	19	58	27	4	40	33	43	36	64	3.85		13	6,200	nw.	38	e.	15	7	7	16	6.4		
Scranton	805	111	119	29.17	30.04	+ .03	46.2	− 0.9	82	19	55	24	6	37	38	42	38	76	3.89	+ 1.2	16	5,840	s.	34	w.	12	5	12	13	6.6	0.5	
Atlantic City	52	37	48	29.99	30.05	+ .05	47.0	− 0.6	66	17	53	27	4	41	28	42	38	74	2.96	0.0	8	6,767	nw.	30	s.	8	11	3	16	6.2		
Cape May	17	13	49	30.04	30.06	+ .07	48.5	+ 0.1	69	22	55	28	4	42	23	44	40	78	2.95	0.0	11	7,420	nw.	40	e.	15	11	9	10	5.4		
Trenton	190	159	183	29.82	30.02		48.5		80	19	58	27	4	39	29	43	36	67	2.57	− 0.7	9	9,463	nw.	50	w.	2	9	8	13	5.7		
Baltimore	123	100	113	29.92	30.05	+ .04	53.0	0.0	85	29	62	31	4	44	38	46	39	63	4.55	+ 1.3	9	5,660	se.	28	e.	15	10	10	10	5.4		
Washington	112	62	85	29.92	30.04	+ .02	53.5	+ 0.4	86	22	64	28	6	43	43	46	39	63	3.20	0.0	9	6,736	nw.	36	nw.	8	10	11	9	5.5		
Lynchburg	681	83	88	29.29	30.04	+ .02	56.7	+ 1.1	88	27	68	28	10	45	41	49	43	64	1.70	− 1.5	7	6,602	nw.	32	nw.	2	12	14	4	4.7		
Mount Weather	1,725	10	75	28.18	30.02	.00	47.9	− 0.5	80	29	57	22	9	39	30	42	38	73	4.07	+ 1.0	9	14,604	nw.	68	nw.	8	5	8	17	7.0	T.	
Norfolk	91	170	205	29.96	30.06	+ .05	55.8	− 0.2	89	29	65	34	9	47	40	50	45	70	1.88	− 1.9	12	9,979	sw.	42	w.	2	12	6	12	5.0		
Richmond	144	11	52	29.91	30.06	+ .04	56.0	− 1.2	92	29	68	30	10	44	39	48	43	66	1.28	− 2.2	7	6,562	s.	31	s.	7	12	11	7	4.6	0.2	
Wytheville	2,293	40	47	27.67	30.05	+ .02	51.5	− 0.5	83	27	64	21	10	39	39	46	43	76	2.00	− 1.7	14	4,502	w.	26	nw.	16	14	11	5	4.0		
South Atlantic States.							**62.9**	**+ 1.6**										**72**	**2.60**	**− 0.8**										**4.9**		
Asheville	2,255	70	84	27.71	30.06	+ .03	55.0	+ 1.1	83	27	66	27	9	44	38	47	42	66	3.13	− 0.9	11	7,345	nw.	39	e.	14	10	13	7	5.1		
Charlotte	773	68	76	29.22	30.06	+ .03	60.6	+ 1.4	88	28	71	35	10	50	29	53	48	70	2.99	− 0.4	9	5,726	sw.	26	w.	29	7	12	11	5.8	T.	
Hatteras	11	12	50	30.05	30.06	+ .05	59.2	+ 1.2	78	30	66	41	9	53	25	54	51	80	4.14	− 0.3	13	9,925	ne.	46	se.	14	14	10	6	4.1		
Manteo	12	12	46				55.2		76	29	63	27	11	47					3.36	− 1.2	9		ne.				16	7	7			
Raleigh	376	103	110	29.65	30.05	+ .02	59.4	+ 0.4	91	29	70	30	10	49	32	51	44	64	2.45	− 1.0	10	6,460	sw.	31	nw.	20	11	9	10	4.8		
Wilmington	78	81	91	29.99	30.07	+ .04	62.0	+ 1.6	90	27	71	37	10	53	26	55	51	75	5.12	+ 2.3	9	6,515	w.	32	ne.	14	10	14	6	4.6		
Charleston	48	11	92	30.01	30.06	+ .03	65.2	+ 1.4	88	27	72	43	10	58	25	59	56	77	2.77	− 0.2	7	8,204	s.	38	ne.	4	14	11	5	3.9		
Columbia, S. C.	351	41	57	29.68	30.06	+ .03	64.4	+ 1.6	92	28	75	37	10	54	32	55	49	63	1.88	− 1.0	8	5,397	sw.	29	sw.	19	11	15	4	4.5		
Augusta	180	89	97	29.86	30.06	+ .03	65.4	+ 2.2	90	29	76	40	10	54	33	58	53	71	1.59	− 1.9	7	4,707	se.	30	w.	20	10	9	11	5.6		
Savannah	65	150	194	29.99	30.06	+ .03	67.4	+ 2.7	89	28	76	43	10	59	25	60	57	78	0.84	− 2.2	6	8,891	s.	40	w.	15	10	11	9	5.2		
Jacksonville	43	96	129	30.01	30.06	+ .02	70.1	+ 2.5	89	30	79	52	10	61	25	62	59	75	0.30	− 2.4	4	6,311	se.	31	sw.	14	11	11	8	5.1		
Florida Peninsula.							**73.8**	**+ 1.0**										**77**	**3.23**	**+ 1.3**										**4.6**		
Key West	22	10	64	30.00	30.02	.00	76.5	+ 1.0	85	28	82	67	7	71	15	70	67	76	1.94	+ 0.6	7	7,533	e.	26	e.	18	17	10	3	3.6		
Miami	25	37	72	30.02	30.05		74.6	+ 0.4	86	15	81	57	16	68	23	68	65	75	5.24	+ 2.6	9	6,396	e.	25	sw.	20	8	9	13	6.3		
Sand Key	23	39	72	29.98	30.00	− .02	75.0		81	7	78	68	5	73	12	71	69	81	1.46		8	10,147	e.	41	s.	13	17	9	4	4.0		
Tampa	35	79	96	30.01	30.05	− .01	71.7	+ 1.1	87	27	80	54	11	63	28	65	62	76	2.50	+ 0.6	8	4,853	ne.	21	e.	18	10	11	9	5.1		
Titusville	44	6		30.01	30.06		72.4	+ 1.4	89	28	81	53	16	64	30				2.77		9		se.				17	7	6	4.2		
East Gulf States.							**65.3**	**+ 0.7**										**69**	**2.92**	**− 1.2**										**5.1**		
Atlanta	1,174	190	216	28.84	30.07	+ .04	61.8	+ 0.7	85	28	72	33	9	52	38	53	47	63	3.16	− 0.5	6	8,375	nw.	40	nw.	20	12	7	11	5.1		
Macon	370	78	87	29.65	30.04	+ .01	65.0	+ 1.9	89	28	77	35	10	53	36	56	50	64	0.84	− 2.6	7	4,574	nw.	30	nw.	19	13	10	7	4.6		
Thomasville	273	8	57	29.75	30.05	+ .02	68.6	+ 1.9	90	28	81	40	10	56	36	59	55	71	1.78	− 1.9	4	3,730	s.	18	s.	8	13	8	9	4.9		
Pensacola	56	140	182	29.99	30.05	+ .03	67.4	− 0.3	82	2	74	39	10	61	28	61	58	77	1.10	− 2.1	7	8,758	se.	36	se.	11	6	11	13	6.1		
Anniston	741	9	57	29.28	30.07	+ .04	61.4	+ 1.0	88	17	74	28	10	49	40				4.16	+ 0.5	8	3,949	s.	22	w.	15	10	15	5	4.7		
Birmingham	700	11	48	29.31	30.07	+ .05	62.8	− 0.7	88	17	73	31	10	52	36	53	46	60	4.46	+ 0.8	10	4,797	s.	26	s.	18	12	11	7	4.4		
Mobile	57	125	161	29.99	30.05	+ .03	67.8	+ 1.8	84	30	76	39	10	60	26	61	57	76	1.77	− 2.6	10	7,036	n.	30	nw.	8	7	19	4	4.6		
Montgomery	223	100	112	29.81	30.06	+ .03	65.8	+ 0.6	88	17	77	35	10	55	33	57	51	65	3.19	− 1.1	6	4,686	se.	31	nw.	8	13	13	4	4.2		
Meridian	375	85	93	29.65	30.05	+ .03	63.9	− 0.2	87	17	75	32	10	53	36	56	51	70	3.18	− 1.9	11	3,495	n.	27	se.	19	7	4	19	6.8		
Vicksburg	247	62	74	29.78	30.06	+ .06	65.4	+ 0.2	86	17	75	38	10	56	29	57	52	68	3.11	− 2.0	8	4,931	se.	24	se.	18	9	10	11	5.6		
New Orleans	51	90	121	29.98	30.03	+ .03	68.9	+ 1.0	85	16	77	43	10	61	23	62	58	76	5.34	+ 0.4	8	6,287	se.	33	nw.	18	9	11	10	5.3		
West Gulf States.							**64.3**	**− 1.4**										**73**	**4.65**	**+ 1.2**										**5.8**		
Shreveport	249	77	93	29.77	30.04	+ .07	64.7	− 1.1	88	16	74	36	9	56	29	57	53	71	3.35	− 1.2	10	5,543	se.	26	s.	17	8	9	13	5.9		
Bentonville	1,303	11	44	28.64	30.01	+ .05	56.9	0.0	84	16	67	23	9	46	36				1.99	− 1.9	8	4,671	s.	40	s.	17	14	6	10	5.0		
Fort Smith	457	79	94	29.53	30.01	+ .05	61.6	− 0.1	90	16	72	30	9	52	36	53	47	65	2.57	− 1.3	10	5,950	e.	50	sw.	24	11	6	13	5.8		
Little Rock	357	139	147	29.67	30.04	+ .06	61.8	− 0.9	89	16	71	31	9	53	35	53	47	64	5.19	+ 0.7	9	6,682	s.	32	nw.	19	7	14	9	5.6		
Brownsville	57	3	40				71.6		87	27	80	41	10	63	34				1.16		10		s.									
Corpus Christi	20	69	77	29.96	29.98	+ .03	68.4	− 2.5	89	15	74	41	9	63	30	64	62	85	5.32	+ 3.5	10	10,719	e.	40	se.	26	4	14	12	6.3		
Dallas	512	109	117	29.46	30.00		62.9		89	16	73	30	9	53	37				5.69		13	7,410	se.	38	w.	18	9	9	12	5.6	T.	
Fort Worth	670	106	114	29.28	29.99	+ .05	63.2	− 2.1	90	16	74	30	9	53	39	55	50	69	5.99	+ 3.3	9	8,657	s.	40	s.	17	8	10	12	6.1		
Galveston	54	106	114	29.96	30.02	+ .05	66.7	− 2.0	76	24	71	44	9	62	16	63	61	86	8.54	+ 5.4	10	8,835	s.	38	s.	27	8	12	10	5.8		
Houston	138	111	121	29.86	30.01		67.9	− 1.7	86	15	76	38	9	60	28				3.26		9	6,556	se.	35	se.	27	7	11	12	6.6		
Palestine	510	64	72	29.47	30.01	+ .05	64.8	− 1.1	88	15	74	34	9	56	34	57	52	72	3.28	− 0.8	8	5,631	s.	27	se.	26	10	8	12	5.6		
San Antonio	701	80	91	29.26	29.99	+ .06	66.8	− 2.2	90	15	78	35	9	56	36	59	55	74	5.26	+ 2.3	9	5,047	se.	33	n.	7	13	5	12	5.4		
Taylor	583	55	63	29.40	30.01	+ .06	64.8	− 1.7	92	15	76	31	9	54	39				5.05	+ 1.1	10	7,855	se.	40	s.	17	9	7	14	5.8	T.	

TABLE I.—*Climatological data for United States Weather Bureau stations, April, 1914*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Pressure in inches: Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Temperature of the air, in degrees Fahrenheit: Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches: Total.	Departure from normal.	Days with 0.01 or more.	Wind: Total movement, miles.	Prevailing direction.	Maximum velocity: Miles per hour.	Direction.	Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
Ohio Valley and Tennessee.							**54.5**	**− 0.2**										**68**	**3.62**	**0.0**										**6.3**		
Chattanooga	762	189	213	29.26	30.08	+ .05	60.5	+ 0.5	85	26	71	32	9	50	38	52	45	63	5.31	+ 0.9	12	6,470	n.	41	sw.	18	7	13	10	5.7	.....	....
Knoxville	996	93	100	29.00	30.06	+ .03	58.2	+ 0.8	88	28	69	29	9	47	38	50	44	64	4.50	− 0.1	11	4,097	ne.	26	sw.	1	6	11	13	6.4	.....	....
Memphis	399	76	97	29.66	30.08	+ .08	61.1	− 0.7	86	17	70	32	9	52	33	53	47	65	2.90	− 1.9	8	6,604	s.	28	n.	7	11	6	13	5.2	.....	....
Nashville	546	168	191	29.49	30.08	+ .07	58.6	− 0.5	88	17	69	27	9	49	39	51	45	64	3.83	− 0.5	11	7,264	se.	50	ne.	14	6	13	11	5.9	.....	....
Lexington	989	75	102	28.98	30.06	+ .04	53.7	0.0	83	27	63	23	9	44	33	....	....	....	2.23	− 1.1	8	7,335	se.	39	sw.	1	8	9	13	6.1	T.	....
Louisville	525	219	255	29.48	30.07	+ .06	55.7	− 0.5	83	17	65	25	9	47	35	49	43	68	2.13	− 1.9	10	9,182	n.	58	s.	18	6	11	13	6.4	T.	....
Evansville	431	72	82	29.58	30.06	+ .06	55.4	− 1.0	81	27	64	27	9	47	35	49	43	66	2.83	− 0.6	11	6,042	s.	38	sw.	18	4	12	14	6.5	.....	....
Indianapolis	822	154	164	29.15	30.05	+ .05	51.9	− 0.5	83	27	61	21	9	43	39	45	39	67	3.21	− 0.3	12	8,115	sw.	48	s.	18	5	6	19	6.9	T.	....
Terre Haute	575	96	129	29.41	30.04	......	53.4	......	83	22	62	24	9	45	38	48	44	76	2.80	......	10	8,309	nw.	42	s.	18	1	16	13	7.2	T.	....
Cincinnati	628	152	160	29.37	30.06	+ .05	53.9	− 0.4	86	27	63	24	9	44	33	47	42	68	3.07	+ 0.1	10	5,242	w.	29	sw.	25	5	9	16	6.9	T.	....
Columbus	824	173	222	29.17	30.05	+ .03	50.7	− 0.3	85	28	60	23	9	41	30	45	41	73	2.48	− 0.4	13	8,862	nw.	48	nw.	1	13	3	14	5.7	0.5	....
Dayton	899	181	216	29.07	30.03	......	51.4	− 0.3	82	27	60	22	9	42	30	45	40	72	2.87	0.0	12	8,560	sw.	42	sw.	18	10	5	15	6.0	T.	....
Pittsburgh	842	353	410	29.13	30.05	+ .03	49.4	− 1.6	86	28	59	23	9	40	33	43	37	66	3.98	+ 1.1	14	8,996	nw.	61	sw.	19	5	7	18	7.0	3.5	....
Elkins	1,940	41	50	27.99	30.06	+ .03	49.2	+ 0.5	85	28	61	20	10	37	49	43	39	74	6.97	+ 2.7	18	3,278	w.	27	w.	1	7	9	14	6.5	T.	....
Parkersburg	638	77	84	29.41	30.07	+ .04	53.9	+ 0.9	89	28	64	26	10	44	38	46	41	69	4.38	+ 1.5	14	4,948	n.	36	nw.	25	8	8	14	5.9	T.	....
Lower Lake Region.							**43.4**	**− 1.7**										**74**	**3.71**	**+ 1.4**										**6.5**		
Buffalo	767	247	280	29.18	30.03	+ .02	40.2	− 2.1	74	18	48	20	9	33	32	38	34	81	3.24	+ 0.8	19	12,074	w.	58	w.	9	6	6	18	6.9	9.2	....
Canton	448	10	61	29.53	30.02	......	39.5	− 3.0	77	19	48	16	13	31	30	....	....	....	3.56	+ 1.3	12	9,602	w.	56	sw.	12	12	7	11	5.2	4.6	....
Oswego	335	76	91	29.65	30.02	+ .01	40.4	− 2.8	81	19	47	21	13	34	36	37	32	76	3.98	+ 1.7	16	8,113	s.	32	nw.	12	7	10	13	6.4	5.5	....
Rochester	523	86	102	29.46	30.05	+ .04	42.0	− 1.9	81	19	50	23	9	34	37	37	31	68	3.72	+ 1.3	17	6,629	w.	38	w.	12	7	7	16	6.8	7.2	....
Syracuse	597	97	113	29.39	30.04	+ .03	41.5	− 2.9	81	19	50	21	13	34	38	37	32	72	4.27	+ 2.0	18	8,821	nw.	45	nw.	12	7	7	16	6.6	6.1	....
Erie	714	92	102	29.25	30.03	+ .01	43.0	− 1.7	83	18	51	22	9	35	37	39	35	75	3.59	+ 1.2	18	7,844	w.	36	sw.	11	3	11	16	7.1	7.8	....
Cleveland	762	190	201	29.21	30.04	+ .02	45.4	− 0.6	84	28	53	23	9	38	32	41	36	74	4.28	+ 2.0	17	10,404	w.	42	s.	19	6	10	14	6.7	0.9	....
Sandusky	629	62	70	29.35	30.04	+ .02	46.0	− 1.3	85	18	54	22	9	38	32	41	37	74	3.86	+ 1.3	14	10,133	w.	37	n.	8	6	7	17	6.8	0.3	....
Toledo	628	208	246	29.35	30.04	+ .03	46.6	− 0.7	84	18	55	21	9	38	31	41	36	70	4.18	+ 1.9	13	11,748	sw.	52	sw.	19	9	7	14	6.0	0.2	....
Fort Wayne	856	113	124	29.10	30.04	......	47.8	− 1.5	83	27	58	19	9	38	39	43	39	75	3.25	......	9	7,982	sw.	39	sw.	19	5	10	15	6.6	T.	....
Detroit	730	218	258	29.23	30.04	+ .02	44.8	− 0.7	83	28	54	19	9	36	34	40	34	70	2.44	+ 0.1	11	9,327	w.	42	w.	25	10	9	11	6.0	1.8	....
Upper Lake Region.							**39.3**	**− 1.5**										**74**	**3.03**	**+ 0.7**										**6.1**		
Alpena	609	13	92	29.35	30.03	+ .01	36.4	− 1.6	82	18	44	15	9	29	42	33	29	77	1.91	− 0.3	12	9,296	nw.	41	w.	11	5	16	9	6.1	2.7	....
Escanaba	612	54	60	29.34	30.03	+ .01	35.2	− 2.0	55	18	43	11	8	28	24	31	27	76	4.54	+ 2.5	15	7,928	n.	38	ne.	28	9	10	11	5.9	2.1	....
Grand Haven	632	54	92	29.32	30.02	+ .01	42.6	− 1.4	79	27	52	19	8	34	37	38	34	76	2.41	0.0	15	8,881	w.	36	s.	18	11	11	8	4.9	4.8	....
Grand Rapids	707	70	87	29.25	30.03	+ .01	45.6	− 0.6	84	18	56	19	9	36	39	40	34	69	1.97	− 0.5	12	5,685	w.	26	w.	9	5	14	11	6.2	4.5	....
Houghton	684	62	72	29.28	30.03	+ .01	34.7	− 2.2	60	18	43	12	8	26	39	....	....	....	5.24	+ 3.2	19	7,207	se.	45	w.	11	7	10	13	6.1	18.1	T.
Lansing	878	11	62	29.07	30.03	......	44.7	− 0.9	84	18	55	16	9	34	36	39	34	72	2.90	+ 0.4	14	5,945	se.	28	sw.	19	7	8	15	6.7	4.1	....
Ludington	637	60	66	29.31	30.02	......	40.0	......	76	27	48	18	8	32	33	37	32	76	1.39	......	11	8,630	n.	46	sw.	18	9	9	12	5.9	5.2	....
Marquette	734	77	111	29.24	30.06	+ .04	35.1	− 2.4	66	15	43	13	8	27	35	31	26	75	6.80	+ 4.8	18	7,771	nw.	43	sw.	11	7	10	13	6.7	18.5	0.1
Port Huron	638	70	120	29.32	30.02	.00	42.0	− 0.2	82	18	50	18	9	33	37	38	34	73	2.04	0.0	11	8,732	s.	32	w.	9	5	13	12	6.3	2.2	....
Saginaw	641	48	82	29.32	30.02	......	43.5	......	85	18	54	18	8	33	39	39	35	77	1.30	− 1.4	11	7,771	nw.	35	sw.	10	6	9	15	6.5	2.3	....
Sault Sainte Marie	614	11	61	29.33	30.04	+ .01	34.0	− 1.7	66	18	42	10	13	26	33	30	26	76	4.71	+ 2.6	17	7,760	e.	40	nw.	12	9	6	15	6.3	15.8	....
Chicago	823	140	310	29.13	30.03	+ .03	48.3	+ 2.4	81	21	56	20	8	40	47	42	36	66	1.07	− 1.8	8	10,046	sw.	48	s.	18	10	9	11	5.6	0.1	....
Green Bay	617	109	144	29.32	29.99	− .02	40.5	− 0.2	80	18	49	14	8	32	33	36	32	75	2.75	+ 0.3	14	9,243	n.	46	s.	10	6	11	13	7.0	5.7	....
Milwaukee	681	119	133	29.27	30.01	+ .02	43.0	+ 1.2	80	18	51	16	8	35	38	38	32	69	1.89	− 0.8	11	6,479	se.	43	sw.	10	9	11	10	5.8	2.0	....
Duluth	1,133	11	47	28.80	30.05	+ .04	33.6	− 4.8	67	15	41	9	8	26	36	30	26	77	2.90	+ 0.8	11	10,859	ne.	51	ne.	28	9	9	12	5.9	7.5	T.
North Dakota.							**40.9**	**+ 0.2**										**69**	**1.38**	**− 0.5**										**5.9**		
Moorhead	940	8	57	29.03	30.06	+ .07	40.2	− 1.2	71	17	51	14	11	30	42	36	33	78	2.97	+ 0.6	12	7,407	n.	36	n.	18	12	7	11	5.1	2.1	....
Bismarck	1,674	8	57	28.27	30.08	+ .11	43.1	+ 0.5	76	23	55	12	7	31	46	37	30	67	0.92	− 1.0	8	8,847	n.	44	nw.	10	7	9	14	6.1	7.0	T.
Devils Lake	1,482	11	44	28.44	30.05	+ .06	37.4	− 0.8	69	20	48	8	7	27	40	33	27	70	1.21	− 0.8	9	9,894	n.	52	n.	18	8	6	16	6.5	3.0	....
Williston	1,872	40	47	28.03	30.04	+ .08	42.8	+ 2.3	77	15	54	12	7	31	40	36	28	61	0.43	− 0.8	5	6,877	n.	42	nw.	20	6	13	11	5.8	2.7	....
Upper Mississippi Valley.							**50.5**	**0.0**										**68**	**2.40**	**− 0.6**										**6.3**		
Minneapolis	918	102	208	......	......	......	44.7	......	77	17	54	19	8	35	35	....	....	....	3.69	+ 1.2	10	9,816	nw.	44	n.	19	7	9	14	6.4	3.4	....
St. Paul	837	201	236	29.09	30.00	+ .01	44.4	− 1.3	75	17	54	18	8	35	36	39	33	69	3.73	+ 1.4	11	10,370	n.	48	se.	17	6	13	11	5.8	3.5	....
La Crosse	714	11	48	29.23	30.01	+ .03	46.8	− 0.5	79	26	57	17	8	37	37	....	....	....	3.36	+ 1.1	12	4,807	se.	30	sw.	18	5	6	19	7.1	1.8	....
Madison	974	70	78	28.95	30.02	+ .03	45.1	+ 0.6	78	27	55	15	8	36	37	39	33	67	1.84	− 0.5	11	8,090	nw.	35	sw.	10	8	5	17	6.7	0.3	....
Charles City	1,015	10	49	28.92	30.01	+ .03	46.3	0.0	80	17	56	20	9	36	38	41	36	76	2.88	0.0	13	6,458	nw.	30	w.	10	9	11	10	5.6	T.	....
Davenport	606	71	79	29.35	30.01	+ .03	50.0	− 0.2	83	26	60	20	8	40	37	43	37	65	0.89	− 2.0	6	6,838	w.	39	sw.	18	7	11	12	6.2	T.	....
Des Moines	861	84	97	29.08	30.00	+ .03	50.4	− 0.2	84	26	60	23	9	41	37	43	37	67	1.52	− 1.5	10	6,634	sw.	36	sw.	24	6	8	16	6.7	0.5	....
Dubuque	698	81	96	29.26	30.02	+ .04	48.5	− 0.4	80	21	58	19	8	39	34	42	36	64	1.53	− 1.4	9	5,915	nw.	32	s.	18	5	10	15	6.5	T.	....
Keokuk	614	64	78	29.35	30.02	+ .04	52.3	+ 0.3	85	26	62	25	9	43	35	46	40	67	1.94	− 1.4	7	6,244	w.	39	sw.	18	7	13	10	5.8	T.	....
Cairo	356	87	93	29.66	30.04	+ .05	58.0	− 0.3	83	17	66	29	9	50	31	52	47	71	2.64	− 0.9	10	7,655	s.	39	s.	18	6	9	15	6.2	T.	....
Peoria	609	11	45	29.36	30.03	+ .04	51.2	+ 0.3	84	26	61	22	8	41	39	44	39	67	2.10	− 1.2	7	5,887	s.	30	s.	10	11	9	10	5.3	T.	....
Springfield, Ill.	644	10	91	29.33	30.02	+ .04	54.0	+ 2.0	85	26	62	25	9	45	39	47	41	66	2.99	− 0.3	7	6,431	s.	36	s.	18	5	8	17	6.8	T.	....
Hannibal	534	74	109	29.44	30.02	+ .04	53.6	0.0	86	26	63	24	9	44	33	....	....	....	2.51	− 0.7	10	7,372	sw.	43	sw.	18	11	7	12	5.9	T.	....
St. Louis	567	265	303	29.42	30.03	+ .05	56.4	+ 0.3	82	16	65	26	9	48	38	49	43	65	1.92	− 1.6	7	9,918	nw.	58	sw.	18	6	16	8	5.7	T.	....
Missouri Valley.							**51.0**	**+ 0.5**										**65**	**2.30**	**− 0.8**										**5.7**		
Columbia, Mo.	784	11	84	29.19	30.03	+ .05	54.2	− 0.1	86	26	64	24	9	45	34	....	....	....	1.74	− 2.0	11	6,323	s.	35	sw.	18	6	5	19	7.0	T.	....
Kansas City	963	161	181	28.98	30.02	+ .06	55.2	+ 0.9	83	21	64	25	8	46	35	48	42	67	1.76	− 1.5	11	9,709	s.	44	n.	7	7	15	8	5.6	.....	....
St. Joseph	967	11	49	28.97	30.01	......	54.1	......	85	21	64	24	8	44	38	46	40	67	2.54	......	8	6,827	s.	36	nw.	19	9	7	14	5.9	T.	....
Springfield, Mo.	1,324	98	104	28.63	30.03	+ .06	54.8	− 0.9	82	16	64	25	9	46	32	48	41	65	3.63	− 0.2	12	7,613	s.	32	s.	17	11	9	10	5.1	T.	....
Iola	984	11	50	28.95	30.00	+ .05	55.0	+ 0.8	87	25	66	24	9	44	41	....	....	....	1.68	− 1.1	8	6,613	s.	32	n.	7	12	10	8	4.6	.....	....
Topeka	983	85	101	......	......	......	54.4	+ 0.7	87	21	65	24	8	44	42	....	....	....	1.30	− 1.4	9	8,037	s.	35	sw.	10	7	14	9	5.4	T.	....
Lincoln	1,189	11	84	28.72	29.99	+ .05	52.3	+ 1.6	84	26	63	22	8	41	42	44	38	66	2.34	− 0.4	7	9,470	n.	55	nw.	19	9	10	11	5.7	T.	....
Omaha	1,105	115	121	28.82	30.00	+ .05	51.8	+ 1.3	85	17	62	22	8	42	37	45	38	66	3.13	+ 0.1	10	7,124	nw.	37	nw.	19	11	7	12	5.6	T.	....
Valentine	2,598	47	54	27.29	30.03	+ .09	45.8	+ 0.4	82	16	58	11	8	34	46	38	30	65	3.53	+ 1.2	9	8,439	nw.	40	s.	22	8	12	10	5.5	0.1	....
Sioux City	1,135	94	164	28.78	30.00	+ .05	48.4	− 0.1	84	17	59	18	8	38	39	41	34	64	2.12	− 0.6	7	10,644	nw.	52	nw.	10	9	10	11	5.7	T.	....
Huron	1,306	56	67	28.62	30.04	+ .08	45.2	+ 0.6	85	16	56	15	9	34	47	39	31	63	2.96	+ 0.3	9	9,657	nw.	46	nw.	18	8	7	15	6.0	0.8	....
Pierre	1,572	70	75	28.37	30.06	+ .11	47.4	+ 0.9	80	15	58	18	8	37	38	39	30	57	1.78	− 0.2	7	8,878	nw.	52	nw.	18	5	14	11	6.1	0.5	....
Yankton	1,233	49	57	28.66	30.00	+ .05	47.8	+ 0.4	84	16	59	18	8	37	49	....	....	....	1.60	− 1.2	6	7,233	nw.	37	nw.	18	7	8	15	6.4	T.	....

TABLE I.—*Climatological data for United States Weather Bureau stations, April, 1914*—**Continued.**

Districts and stations.	Elevation of instruments.			Pressure in inches.			Temperature of the air, in degrees Fahrenheit.									Mean wet thermometer.	Mean temperature of the dew point.	Mean relative humidity, per cent.	Precipitation, inches.			Wind.					Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow on ground at end of month.
	Barometer above sea level, feet.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.				Total.	Departure from normal.	Days with 0.01 or more.	Total movement, miles.	Prevailing direction.	Maximum velocity: Miles per hour.	Direction.	Date.						
Northern Slope.							**44.0**	**+ 1.2**										**66**	**1.73**	**− 0.1**										**6.5**		
Havre	2,505	11	44	27.38	30.03	+ .10	44.9	+ 2.2	78	15	58	15	8	32	50	38	30	64	0.04	− 1.0	2	6,481	e.	36	w.	9	8	9	13	5.8	T.	....
Helena	4,110	87	114	25.81	30.04	+ .08	44.0	+ 2.0	65	19	53	26	8	35	32	37	30	62	1.35	+ 0.2	11	6,114	sw.	46	sw.	13	3	10	17	7.1	8.6	....
Kalispell	2,962	11	34	26.94	30.02	+ .06	44.8	+ 2.3	68	22	56	29	26	34	34	38	31	64	1.21	+ 0.2	11	3,447	sw.	18	sw.	19	7	15	8	5.7	T.	....
Miles City	2,371	26	48	27.50	30.08	+ .12	47.8	+ 3.1	80	15	60	19	8	36	42	40	33	63	0.20	− 1.0	7	5,098	s.	30	n.	17	8	15	7	5.3	0.2	....
Rapid City	3,234	46	50	26.62	30.07	+ .12	44.0	+ 0.5	77	15	54	11	8	34	37	38	30	63	1.58	− 0.7	15	5,970	n.	31	nw.	17	4	6	20	7.5	0.5	....
Cheyenne	6,088	58	64	23.97	29.99	+ .08	40.2	− 1.4	67	15	50	12	8	31	34	34	29	68	2.58	+ 0.7	15	9,685	nw.	60	w.	23	4	10	16	7.3	5.1	....
Lander	5,372	60	68	24.63	30.03	+ .09	42.0	− 0.2	70	19	53	22	1	31	38	35	29	68	5.36	+ 2.9	14	3,724	nw.	40	sw.	15	5	8	17	7.1	11.1	....
Sheridan	3,790	10	47	26.13	30.06	......	43.2	......	75	15	55	13	8	32	44	37	32	72	2.75	......	16	5,546	nw.	38	nw.	9	3	10	17	7.3	4.5	....
Yellowstone	6,200	11	48	23.86	30.03	+ .07	38.0	+ 1.0	58	22	48	19	11	28	35	32	27	71	1.74	+ 0.4	11	5,619	s.	28	nw.	13	6	9	15	6.7	3.6	....
North Platte	2,821	11	51	27.07	30.01	+ .09	50.0	+ 1.0	84	20	64	13	8	36	46	41	34	63	1.48	− 0.7	10	6,270	n.	32	nw.	16	12	9	9	5.3	T.	....
Middle Slope.							**53.0**	**− 0.7**										**66**	**2.30**	**0.0**										**5.4**		
Denver	5,291	129	172	24.69	29.96	+ .06	46.6	− 1.1	78	20	58	17	8	36	37	39	32	63	3.75	+ 1.6	16	5,813	ne.	42	w.	23	3	17	10	6.7	9.0	....
Pueblo	4,685	80	86	25.25	29.94	+ .06	49.0	− 1.5	81	25	62	19	9	36	44	39	30	58	3.64	+ 2.2	12	5,366	se.	50	nw.	23	8	13	9	5.7	2.3	....
Concordia	1,398	42	50	28.52	30.00	+ .07	54.2	+ 0.6	90	21	66	19	9	42	41	46	39	64	1.00	− 1.4	6	6,409	s.	32	se.	23	5	16	9	5.8	.....	....
Dodge City	2,509	11	51	27.37	29.97	+ .07	54.2	− 0.2	92	21	68	16	8	40	42	44	37	63	1.28	− 0.6	9	9,268	se.	48	se.	5	12	12	6	4.7	.....	....
Wichita	1,358	139	158	28.54	29.97	+ .04	56.0	− 0.6	87	16	66	26	8	46	32	48	42	65	1.70	− 1.0	10	10,580	s.	52	nw.	18	15	10	5	3.7	T.	....
Oklahoma	1,214	10	47	28.71	29.99	+ .07	58.0	− 1.6	89	16	69	25	9	47	33	50	45	69	2.41	− 0.4	9	12,237	s.	48	se.	17	9	9	12	5.9	.....	....
Southern Slope.							**61.5**	**− 0.9**										**58**	**2.33**	**+ 0.4**										**4.6**		
Abilene	1,738	10	52	28.17	29.97	+ 0.7	63.0	− 1.4	94	16	75	26	9	51	37	53	45	60	5.34	+ 3.1	7	9,716	s.	38	sw.	16	12	6	12	5.6	T.	....
Amarillo	3,676	10	49	26.23	29.95	+ .08	56.0	+ 1.4	88	21	70	20	8	42	41	46	38	64	0.95	− 0.8	10	9,827	sw.	40	ne.	11	15	13	2	3.8	1.8	....
Del Rio	944	8	57	28.97	29.95	+ .06	68.6	− 1.4	93	15	80	34	9	57	38	....	....	....	1.88	− 1.1	4	6,813	se.	52	sw.	25	11	13	6	4.4	.....	....
Roswell	3,566	75	85	26.32	29.90	+ .05	58.4	− 2.2	87	15	73	31	13	44	45	46	32	49	1.14	+ 0.6	5	7,255	s.	48	se.	30	14	9	7	4.4	2.9	....
Southern Plateau.							**58.4**	**+ 0.5**										**42**	**0.29**	**− 0.1**										**3.3**		
El Paso	3,762	110	133	26.12	29.83	.00	64.0	+ 0.2	89	15	78	36	9	50	38	46	23	28	0.47	+ 0.2	1	8,961	w.	50	sw.	16	22	8	0	2.5	.....	....
Santa Fe	7,013	57	62	23.20	29.86	+ .02	48.0	+ 0.4	73	21	60	24	8	36	36	37	24	47	0.44	− 0.4	8	6,818	n.	44	sw.	16	8	16	6	5.2	1.5	....
Flagstaff	6,907	8	57	23.29	29.84	.00	43.9	+ 1.7	72	14	59	22	18	29	45	....	....	....	0.48	......	3	......	sw.	40	sw.	22	11	14	5	....	3.0	....
Phoenix	1,108	76	81	28.70	29.85	− .02	68.5	+ 1.9	97	14	82	45	23	54	40	52	36	35	0.10	− 0.3	1	4,246	e.	31	n.	17	18	8	4	2.9	.....	....
Yuma	141	9	58	29.72	29.87	− .02	71.5	+ 1.4	102	14	87	46	23	56	44	55	42	41	0.27	+ 0.2	1	4,803	w.	30	ne.	17	28	2	0	0.8	.....	....
Independence	3,910	11	42	25.97	29.95	− .05	54.3	− 2.4	84	19	68	29	1	40	40	45	36	57	0.18	0.0	5	5,931	nw.	41	nw.	15	10	13	7	4.9	.....	....
Middle Plateau.							**49.6**	**+ 1.1**										**54**	**1.32**	**+ 0.2**										**5.7**		
Reno	4,532	74	81	25.45	29.98	+ .01	49.0	+ 1.7	77	18	61	27	1	37	43	39	29	52	0.70	+ 0.1	5	5,865	w.	43	w.	9	9	13	8	5.4	T.	....
Tonopah	6,090	12	20	24.00	29.90	......	47.4	......	73	14	57	27	17	38	33	38	26	47	0.50	− 1.2	6	7,092	nw.	40	nw.	16	9	13	8	5.5	T.	....
Winnemucca	4,344	18	56	25.59	29.98	+ .02	48.6	+ 1.5	75	14	61	23	17	36	41	40	32	59	1.32	+ 0.4	10	5,043	sw.	32	nw.	15	7	7	16	6.5	T.	....
Modena	5,479	10	43	24.56	29.90	+ .02	46.8	− 0.1	75	19	60	26	18	34	42	37	28	59	2.17	+ 1.4	12	7,380	sw.	45	s.	22	6	14	10	6.2	1.7	....
Salt Lake City	4,360	147	189	25.56	29.92	.00	51.8	+ 1.7	72	4	61	38	16	43	29	43	36	59	2.84	+ 0.6	11	5,359	nw.	37	e.	30	8	16	6	5.3	T.	....
Durango	6,546	18	56	23.59	29.87	+ .02	47.3	+ 0.9	74	15	62	26	17	33	39	36	27	53	0.77	− 0.4	5	4,586	nw.	34	w.	22	9	13	8	5.1	T.	....
Grand Junction	4,602	43	51	25.31	29.87	− .01	54.1	+ 0.9	80	20	66	33	9	43	33	43	33	52	0.92	+ 0.2	9	5,994	se.	37	sw.	5	6	14	10	5.9	.....	....
Northern Plateau.							**50.4**	**+ 1.4**										**59**	**1.64**	**+ 0.3**										**6.4**		
Baker	3,471	48	53	26.46	30.06	+ .06	46.2	+ 2.7	70	19	57	27	28	35	31	39	32	62	2.02	+ 1.1	13	4,693	nw.	25	nw.	29	11	9	10	5.2	0.2	....
Boise	2,739	78	86	27.15	30.02	+ .04	51.2	+ 1.1	73	19	62	29	28	40	35	43	34	57	1.63	+ 0.4	12	3,916	nw.	26	nw.	16	6	7	17	6.7	.....	....
Lewiston	757	40	48	29.23	30.05	+ .06	53.6	+ 0.7	76	30	65	33	29	42	38	....	....	....	1.63	+ 0.5	10	2,470	e.	24	nw.	26	4	14	12	6.4	.....	....
Pocatello	4,477	46	54	25.43	29.95	+ .01	48.1	+ 1.3	70	19	59	29	26	38	33	40	32	60	1.59	− 0.4	12	5,670	se.	34	sw.	16	3	13	14	7.0	0.1	....
Spokane	1,929	101	110	27.98	30.04	+ .05	49.6	+ 1.9	75	30	60	31	21	39	36	42	35	62	1.45	+ 0.2	8	4,719	ss.	34	w.	19	7	7	16	6.5	T.	....
Walla Walla	1,000	107	115	28.97	30.05	+ .04	53.4	+ 0.6	76	14	64	33	21	43	32	45	36	56	1.54	− 0.2	10	3,662	s.	24	w.	19	5	11	14	6.5	.....	....
North Pacific Coast Region.							**50.4**	**+ 2.1**										**81**	**3.47**	**+ 0.1**										**6.2**		
North Head	211	11	56	29.86	30.09	+ .04	49.4	+ 1.9	66	3	53	42	21	46	18	47	45	88	4.66	+ 1.4	20	11,328	nw.	62	se.	4	9	11	10	5.7	.....	....
Port Crescent	259	8	53	29.79	30.08	+ .06	45.6	+ 0.9	60	8	53	31	16	38	27	....	....	....	1.88	− 0.6	15	3,660	s.	14	sw.	27	3	13	14	6.7	.....	....
Seattle	125	215	250	29.96	30.09	+ .06	51.4	+ 2.0	68	30	59	36	1	44	28	47	44	80	3.31	+ 0.6	14	6,305	s.	55	sw.	26	4	15	11	6.4	.....	....
Tacoma	213	113	120	29.86	30.08	+ .05	50.8	+ 1.9	68	18	59	32	1	42	29	48	46	87	3.20	+ 0.4	13	4,413	sw.	35	sw.	26	4	16	10	6.3	.....	....
Tatoosh Island	86	7	57	29.95	30.05	+ .05	48.6	+ 2.5	59	3	53	41	7	44	14	47	45	89	5.39	− 0.9	17	11,221	e.	54	s.	14	6	9	15	6.8	.....	....
Portland, Oreg.	153	68	106	29.91	30.07	+ .01	53.8	+ 2.6	76	30	63	37	28	45	29	48	42	70	3.08	0.0	18	4,128	nw.	24	w.	4	7	10	13	6.0	.....	....
Roseburg	510	9	57	29.52	30.08	+ .01	53.5	+ 2.6	83	18	64	34	28	43	40	47	42	71	2.50	0.0	14	2,629	s.	28	sw.	26	4	22	4	5.2	.....	....
Middle Pacific Coast Region.							**55.6**	**+ 2.0**										**71**	**1.56**	**− 0.5**										**4.6**		
Eureka	62	73	80	30.03	30.10	− .01	51.9	+ 2.4	70	14	58	39	27	45	27	48	46	82	3.27	− 0.7	12	6,294	n.	38	n.	20	9	12	9	5.4	.....	....
Mount Tamalpais	2,375	11	18	27.57	30.06	+ .01	50.1	+ 0.6	72	18	56	37	21	44	21	45	40	73	1.31	− 0.1	6	12,437	nw.	88	nw.	25	13	7	10	4.9	.....	....
Point Reyes Light	490	7	18	29.50	30.02	......	53.6	+ 5.0	81	18	58	45	21	49	30	....	....	....	1.18	......	7	16,846	nw.	82	nw.	28	12	11	7	4.9	.....	....
Red Bluff	332	50	56	29.67	30.03	.00	59.2	+ 0.1	88	18	69	42	24	50	34	51	43	63	2.41	+ 0.6	10	4,332	se.	28	nw.	15	8	8	14	5.8	.....	....
Sacramento	69	106	117	29.96	30.03	+ .02	58.8	+ 0.8	81	18	67	43	24	50	27	53	47	67	0.70	− 1.3	6	6,038	s.	30	nw.	29	16	9	5	3.7	.....	....
San Francisco	155	200	204	29.88	30.05	.00	58.2	+ 4.5	83	18	65	48	28	52	27	51	46	71	0.99	− 0.8	7	5,223	w.	24	sw.	9	17	8	5	3.5	.....	....
San Jose	141	12	110	29.90	30.05	......	57.5	+ 0.8	86	18	69	38	25	46	38	....	....	....	0.65	− 0.8	5	4,483	nw.	23	w.	15	14	7	9	4.3	.....	....
South Pacific Coast Region.							**60.8**	**+ 2.8**										**69**	**0.65**	**0.4**										**4.4**		
Fresno	327	89	98	29.67	30.03	+ .04	60.8	− 0.4	92	19	72	43	24	49	38	52	45	62	0.59	− 0.1	6	6,082	nw.	31	nw.	10	11	11	8	5.2	.....	....
Los Angeles	338	159	191	29.62	29.99	.00	62.8	+ 5.2	92	19	72	46	22	54	30	54	48	67	0.47	− 0.7	5	4,704	ne.	24	ne.	22	12	5	13	5.1	.....	....
San Diego	87	62	70	29.89	29.98	− .01	61.4	+ 3.2	85	19	68	50	1	54	29	55	51	74	0.85	+ 0.1	4	5,024	nw.	26	sw.	22	18	6	6	3.6	.....	....
San Luis Obispo	201	47	54	29.85	30.07	+ .02	58.2	+ 3.0	90	18	68	38	29	48	43	52	47	74	0.68	− 0.8	3	4,814	n.	25	w.	10	15	9	6	3.9	.....	....
West Indies.																																
San Juan	82	8	54	29.92	30.01	+ .03	76.2	......	85	5	82	69	25	71	15	....	....	....	3.30	− 0.6	22	8,932	se.	35	ne.	22	11	12	7	5.1	.....	....
Panama.																																
Ancon	92	6	69	29.74	29.83	......	82.6	......	95	1	92	72	6	74	23	75	73	79	4.80	+ 2.1	9	6,465	nw.	24	nw.	1	7	16	7	5.7	.....	....
Culebra	404	5	62	29.44	29.86	......	82.3	......	96	9	92	71	28	73	24	74	72	82	0.62	− 2.9	7	6,669	nw.	26	n.	24	3	19	8	6.3	.....	....
Colon	10	5	71	29.86	29.87	......	81.4	......	88	9	85	73	27	78	12	76	75	83	4.12	+ 0.1	18	9,450	n.	30	nw.	28	10	16	4	4.8	.....	....

Table II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during April, 1914, at all stations furnished with self-registering gages.*

Stations.	Date.	Total duration. From—	Total duration. To—	Total amount of precipitation.	Excessive rate. Began—	Excessive rate. Ended—	Amount before excessive rate began.	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Abilene, Tex.	25–26	10.15 p. m.	D. N. a. m.	2.76	10.35 p. m.	10.59 p. m.	.14†	.12†	.25†	.52†	.71†	.80†									
	26	9.40 p. m.	10.30 p. m.	1.89	9.44 p. m.	10.20 p. m.	.02	.23	.64	1.12	1.26	1.54	1.80	1.86	1.87						
Albany, N. Y.	8			1.50														.60			
Alpena, Mich.	28			0.73														.22			
Amarillo, Tex.	6			0.32														.32			
Anniston, Ala.	14			1.26														.62			
Asheville, N. C.	19			0.44														.35			
Atlanta, Ga.	14			1.78														.63			
Atlantic City, N. J.	26			1.26														.51			
Augusta, Ga.	14			0.87														.38			
Baker, Oreg.	22			0.60														.31			
Baltimore, Md.	8			0.99														.62			
Bentonville, Ark.	18			0.40														.23			
Binghamton, N. Y.	19			0.61														.24			
Birmingham, Ala.	29			1.00														.60			
Bismarck, N. Dak.	27–28			0.67														*			
Block Island, R. I.	8–9			0.50														.44			
Boise, Idaho	10			0.41														.14			
Boston, Mass.	8			0.62														.35			
Buffalo, N. Y.	25			0.28														.14			
Burlington, Vt.	7–8			1.34														*			
Cairo, Ill.	26			0.33														.33			
Canton, N. Y.	8			0.84														*			
Charles City, Iowa	24			1.06														.71			
Charleston, S. C.	14	9.58 a. m.	2.15 p. m.	1.58	1.18 p. m.	2.00 p. m.	.14	.13	.27	.60	.84	1.07	1.10	1.22	1.38	1.44					
Charlotte, N. C.	14			1.65														.50			
Chattanooga, Tenn.	19			1.11														.71			
Cheyenne, Wyo.	6–7			0.42†														*			
Chicago, Ill.	27			0.44														.38			
Cincinnati, Ohio	25			0.90														.36			
Cleveland, Ohio	25	5.25 p. m.	6.33 p. m.	0.64	5.52 p. m.	6.14 p. m.	.06	.10	.22	.36	.51	.57									
Columbia, Mo.	27			0.36														.15			
Columbia, S. C.	14			1.20														.32			
Columbus, Ohio	25			0.55														.27			
Concord, N. H.	1			0.61														.21			
Concordia, Kans.	18			0.57														.37			
Corpus Christi, Tex.	3–4	9.22 p. m.	D. N. a. m.	1.22	9.28 p. m.	10.07 p. m.	.02	.07	.11	.22	.33	.38	.52	.68	.73						
	29	8.36 p. m.	D. N. p. m.	1.17	9.32 p. m.	10.17 p. m.	.16	.17	.23	.29	.37	.46	.49	.64	.70	.76					
	30	8.32 a. m.	2.38 p. m.	1.42	11.16 a. m.	11.45 a. m.	.35	.09	.19	.24	.36	.52	.57								
Dallas, Tex.	24–25	10.00 p. m.	3.15 a. m.	1.18	10.07 p. m.	10.45 p. m.	.05	.13	.22	.34	.48	.53	.60	.66	.71						
Davenport, Iowa	28			0.35														.15			
Dayton, Ohio	1			0.79														.37			
Del Rio, Tex.	25	8.30 p. m.	10.20 p. m.	1.20	8.45 p. m.	9.15 p. m.	.03	.62	.77	.94	1.03	1.08	1.13								
Denver, Colo.	26			0.45														.17			
Des Moines, Iowa	26			0.28														.24			
Detroit, Mich.	25			1.17														.56			
Devils Lake, N. Dak.	28–29			0.81†														*			
Dodge City, Kans.	23			0.33														.33			
Dubuque, Iowa	24			0.40														.34			
Duluth, Minn.	28			1.01†														.23			
Durango, Colo.	10–11			0.33†														*			
Eastport, Me.	9			1.13														.39			
Elkins, W. Va.	25			1.37														.55			
El Paso, Tex.	3			0.47														.46			
Erie, Pa.	7–8			1.11														*			
Escanaba, Mich.	28			2.00														.28			
Eureka, Cal.	9			0.99														.40			
Evansville, Ind.	14			1.26														.19			
Flagstaff, Ariz.	22			0.30														*			
Fort Smith, Ark.	27			0.99														.36			
Fort Wayne, Ind.	27			0.79														.47			
Fort Worth, Tex.	24–25	8.57 p. m.	3.14 a. m.	2.27	9.20 p. m.	10.15 p. m.	.02	.07	.21	.49	.60	.67	.73	.87	1.13	1.36	1.68	1.87			
Fresno, Cal.	4			0.34														.21			
Galveston, Tex.	13	D. N. a. m.	8.45 a. m.	0.82	3.11 a. m.	3.34 a. m.	.02	.18	.26	.28	.64	.69									
	27–28	1.55 p. m.	1.15 p. m.	4.61	6.59 p. m.	7.49 p. m.	.25	.06	.07	.22	.36	.38	.44	.51	.57	.73	.79				
					7.49 p. m.	8.39 p. m.		.93	1.13	1.22	1.32	1.35	1.39	1.51	1.55	1.67	1.69				
					8.39 p. m.	9.29 p. m.		1.69	1.73	1.79	2.06	2.29	2.38	2.50	2.54	2.55	2.59				
					9.29 p. m.	10.19 p. m.		2.70	2.75	2.77	2.79	2.81	2.90	2.93	2.94	3.10	3.40				
					10.19 p. m.	10.32 p. m.		3.54	3.81	3.94											
Grand Haven, Mich.	27			0.62														.52			
Grand Junction, Colo.	10			0.38														.13			
Grand Rapids, Mich.	24			0.44														.28			
Green Bay, Wis.	27–28			0.83														*			
Hannibal, Mo.	28			0.64														.38			
Harrisburg, Pa.	25			1.28														.33			
Hartford, Conn.	15			0.88														.24			
Hatteras, N. C.	20	8.26 a. m.	11.40 a. m.	0.82	10.00 a. m.	10.38 a. m.	.03	.17	.25	.28	.33	.41	.52	.58	.65						
Havre, Mont.	19			0.03														.02			
Helena, Mont.	5–6			0.72														*			
Houghton, Mich.	25			0.47														.21			
Houston, Tex.	27	12.15 p. m.	5.45 p. m.	1.74	3.49 p. m.	4.19 p. m.	.31	.07	.22	.43	.69	.98	1.30								
Huron, S. Dak.	23			0.42														.34			
Independence, Cal.	30			0.06														.05			
Indianapolis, Ind.	27			0.29														.29			
Iola, Kans.	26			0.33														.33			
Jacksonville, Fla.	6			0.15														.06			
Kalispell, Mont.	5			0.51														.06			
Kansas City, Mo.	6			0.86														.21			
Keokuk, Iowa	28			0.66														.27			
Key West, Fla.	6			1.04														.64			
Knoxville, Tenn.	19			1.26														.61			
La Crosse, Wis.	24	1.02 p. m.	3.35 p. m.	1.00	2.09 p. m.	2.38 p. m.	.28	.09	.22	.33	.41	.52	.58								
Lander, Wyo.	5			0.67														.39			
Lansing, Mich.	27			0.85														.69			
Lewiston, Idaho	12			0.26														.13			
Lexington, Ky.	19			0.52														.37			
Lincoln, Nebr.	27			0.94														.60			
Little Rock, Ark.	27–28	8.10 p. m.	7.20 a. m.	2.40	6.00 a. m.	7.00 a. m.	1.50	.08	.13	.15	.22	.30	.40	.48	.56	.63	.73	.86			
Los Angeles, Cal.	21			0.07														.05			
Louisville, Ky.	27			0.22														.21			
Ludington, Mich.	24			0.52														.25			

* Self-register does not work during freezing weather.

** Self-register out of order.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during April, 1914, at all stations furnished with self-registering gages*—Continued.

Stations.	Date.	Total duration.		Total amount of precipitation.	Excessive rate.		Amount before excessive rate began.	Depths of precipitation (in inches) during periods of time indicated.													
		From—	To—		Began—	Ended—		5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	40 min.	45 min.	50 min.	60 min.	80 min.	100 min.	120 min.
Lynchburg, Va.	15			0.69														.43			
Macon, Ga.	19			0.27														.21			
Madison, Wis.	24	5.03 p. m.	6.35 p. m.	0.85	5.28 p. m.	6.07 p. m.	.01	.23	.39	.47	.51	.57	.62	.66	.74						
Marquette, Mich.	28			3.04														.33			
Memphis, Tenn.	25			0.46														.31			
Meridian, Miss.	28–29	D.N. p. m.	D.N. a. m.	1.23	12.58 a. m.	1.22 a. m.	.16	.31	.55	.69	.83	.92									
Miami, Fla.	2	11.43 a. m.	12.10 p. m.	0.59	11.46 a. m.	12.02 p. m.	.01	.20	.46	.52	.58										
		12.57 p. m.	2.20 p. m.	2.05	1.03 p. m.	1.39 p. m.	.05	.21	.74	1.20	1.52	1.69	1.80	1.97	1.99						
Milwaukee, Wis.	24			1.05														1.02			
Minneapolis, Minn.	24			1.17														.41			
Mobile, Ala.	19			0.77														.31			
Modena, Utah	6			0.36														.18			
Montgomery, Ala.	13–14	6.35 p. m.	6.15 a. m.	1.07	1.21 a. m.	1.41 a. m.	.15	.08	.28	.39	.53										
Moorhead, Minn.	27–28			1.44														*			
Mount Tamalpais, Cal.	4			0.54														.32			
Mount Weather, Va.	25			0.87														.49			
Nantucket, Mass.	16			0.91														.48			
Nashville, Tenn.	19			0.63														.28			
New Haven, Conn.	25–26			1.44														*			
New Orleans, La.	18–19	7.05 p. m.	D. N. a. m.	4.80	8.41 p. m.	10.40 p. m.	.32	.09	.22	.41	.55	.61	.70	.76	.83	.88	.91	1.02	2.17	3.38	3.97
New York, N. Y.	26			1.12														.25			
Norfolk, Va.	20			0.60														.43			
Northfield, Vt.	8			1.07														.15			
North Head, Wash.	26			1.04														.21			
North Platte, Nebr.	22			0.28														.27			
Oklahoma, Okla.	17	8.30 p. m.	9.40 p. m.	0.73	8.46 p. m.	9.11 p. m.	.03	.07	.10	.18	.33	.60									
Omaha, Nebr.	23	8.50 p. m.	D. N. p. m.	1.26	9.17 p. m.	10.11 p. m.	.04	.05	.16	.32	.38	.49	.65	.90	.92	.97	1.05	1.19			
Oswego, N. Y.	7–8			0.86														*			
Palestine, Tex.	25	2.15 a. m.	6.20 a. m.	1.34	2.26 a. m.	3.16 a. m.	.01	.18	.24	.31	.38	.44	.52	.61	.68	.72	.79				
Parkersburg, W. Va.	25			0.99														.59			
Pensacola, Fla.	11			0.34														.27			
Peoria, Ill.	28			0.57														.31			
Philadelphia, Pa.	8			0.56														.51			
Phoenix, Ariz.	22			0.10														.05			
Pierre, S. Dak.	23			0.56														.23			
Pittsburgh, Pa.	25			0.91														.29			
Pocatello, Idaho	15			0.49														.26			
Point Reyes Light, Cal.	4			0.26														.14			
Port Huron, Mich.	1			0.64														.23			
Portland, Me.	2			0.54														.28			
Portland, Oreg.	14			0.69														.12			
Providence, R. I.	25–26			1.33														*			
Pueblo, Colo.	6			1.26														.53			
Raleigh, N. C.	20			1.60														.70			
Rapid City, S. Dak.	25–26			0.41														.11			
Reading, Pa.	8			0.60														.41			
Red Bluff, Cal.	9			1.27														.54			
Reno, Nev.	21			0.65														.22			
Richmond, Va.	8			0.17														.15			
Rochester, N. Y.	25			0.65														.17			
Roseburg, Oreg.	9			0.90														.19			
Roswell, N. Mex.	30			0.53														.44			
Sacramento, Cal.	4			0.48														.26			
Saginaw, Mich.	27			0.15														.10			
St. Joseph, Mo.	18			0.67														.28			
St. Louis, Mo.	27			0.29														.24			
St. Paul, Minn.	18			1.07														.48			
Salt Lake City, Utah	16			0.76														.24			
San Antonio, Tex.	3	12.45 p. m.	7.15 p. m.	1.90	4.22 p. m.	4.37 p. m.	.46	.31	.93	1.14											
	27	5.30 a. m.	10.10 a. m.	1.29	7.46 a. m.	8.15 a. m.	.19	.09	.18	.30	.39	.55	.74								
San Diego, Cal.	22			0.46														.20			
Sand Key, Fla.	13	10.12 p. m.	11.34 p. m.	1.06	10.17 p. m.	10.45 p. m.	.01	.15	.41	.62	.78†	.86†	.91†								
Sandusky, Ohio	24			0.49														.35			
San Francisco, Cal.	4			0.46														.35			
San Jose, Cal.	4			0.35														.20			
San Luis Obispo, Cal.	4			0.40														.12			
Sante Fe, N. Mex.	10			0.19														*			
Sault Ste. Marie, Mich.	28			2.12†														*			
Savannah, Ga.	14			0.37														.21			
Scranton, Pa.	8			0.87														.20			
Seattle, Wash.	27			0.71														.20			
Sheridan, Wyo.	6–7			0.90														*			
Shreveport, La.	11			0.42														.37			
Sioux City, Iowa	23			0.74														.57			
Spokane, Wash.	15			0.21														.10			
Springfield, Ill.	1			0.58														.33			
Springfield, Mo.	24–25			0.95														*			
Syracuse, N. Y.	7–8			0.98														*			
Tacoma, Wash.	26			0.40														.25			
Tampa, Fla.	14			0.90														.60			
Tatoosh Island, Wash.	2			0.41														.19			
Taylor, Tex.	27			1.24														.62			
Terre Haute, Ind.	1			0.68														.39			
Thomasville, Ga.	14	12.26 p. m.	1.28 p. m.	1.10	12.47 p. m	1.20 p. m.	.03	.12	.44	.71	.92	.97	1.00	1.07							
Toledo, Ohio	24			1.03														.61			
Tonopah, Nev.	21–22			0.26														*			
Topeka, Kans.	27			0.45														.33			
Valentine, Nebr.	26			1.23														.43			
Vicksburg, Miss.	18			1.00														.43			
Walla Walla, Wash.	15			0.66														.26			
Washington, D. C.	8			0.68														.33			
Wichita, Kans.	17			0.54														.36			
Williston, N. Dak.	28			0.30														*			
Wilmington, N. C.	1			1.64														.63			
Winnemucca, Nev.	4			0.15														.11			
Wytheville, Va.	19			0.28														.27			
Yankton, S. Dak.	23			0.43														.27			
Yellowstone Park, Wyo.	15–16			0.45														*			

† Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, April, 1914.*

Stations.	Pressure.			Temperature.						Precipitation.		
	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷ 2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Inches.	*Inches.*	*Inches.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*Inches.*	*Inches.*	*Inches.*
St. Johns, Newfoundland	29.58	29.72	−.17	29.8	−4.7	35.7	23.9	50	8	3.02	−1.14	14.0
Sydney, Cape Breton Island	29.88	29.92	+.03	32.4	−2.6	40.5	24.3	62	4	4.82	+0.97	39.0
Halifax, Nova Scotia	29.86	29.97	+.01	37.8	0.0	47.8	27.9	70	17	3.33	−0.85	5.8
Yarmouth, Nova Scotia	29.93	30.00	+.04	37.7	−1.2	44.9	30.5	59	20	2.89	−0.50	2.4
Charlottetown, Prince Edward Island	29.90	29.94	+.04	32.1	−3.1	39.2	25.1	57	8	3.04	+0.39	17.7
Chatham, New Brunswick	29.96	29.98	+.08	32.8	−2.7	43.9	21.7	64	−2	3.16	+0.53	21.6
Father Point, Quebec	29.96	29.98	+.05	30.2	−3.0	36.6	23.9	46	9	1.54	−0.04	9.8
Quebec, Quebec	29.67	30.01	+.02	32.8	−2.3	40.9	24.7	56	5	2.18	+0.09	9.8
Montreal, Quebec	29.80	30.01	+.01	38.0	−1.7	45.6	30.4	74	14	1.57	−0.67	4.5
Stonecliffe, Ontario	29.39	30.01	−.01	35.9	−2.0	45.9	25.9	68	6	2.31	+0.75	3.1
Ottawa, Ontario	29.75	30.08	+.06	38.0	−2.0	46.1	29.9	68	14	2.79	+1.29	11.7
Kingston, Ontario	29.73	30.05	+.03	39.1	−0.9	46.2	32.0	64	17	3.56	+1.77	1.4
Toronto, Ontario	29.61	30.00	−.02	41.5	+0.7	48.9	34.1	67	22	1.92	−0.45	1.0
White River, Ontario	28.68	30.03	−.01	26.3	−6.7	40.5	12.1	62	−15	1.62	+0.37	11.0
Port Stanley, Ontario	29.38	30.04	+.02	41.0	0.0	48.6	33.4	64	20	3.03	+0.56	4.7
Southampton, Ontario	29.30	....	....	39.2	+0.5	47.4	31.0	77	18	1.84	+0.04	2.1
Parry Sound, Ontario	29.30	30.00	−.02	37.6	0.0	47.4	27.8	73	11	3.29	+1.38	5.5
Port Arthur, Ontario	29.33	30.06	+.03	32.0	−1.5	42.8	21.3	62	4	1.37	−0.35	3.7
Winnipeg, Manitoba	29.23	30.08	+.06	36.1	+0.2	45.3	26.9	66	9	0.75	−0.30	3.6
Minnedosa, Manitoba	28.23	30.09	+.08	36.0	0.0	47.3	24.8	70	3	1.64	+0.58	2.9
Qu'Appelle, Saskatchewan	27.74	30.01	+.02	38.4	+1.0	50.1	26.6	70	5	0.89	−0.16	8.4
Medicine Hat, Alberta	27.69	29.98	+.06	47.8	+3.3	61.1	34.5	77	20	T.	−0.74	T.
Swift Current, Saskatchewan	27.39	29.98	+.02	41.8	+0.5	55.7	27.9	76	11	0.40	−0.53	0.8
Calgary, Alberta	26.41	29.96	+.06	42.8	+3.2	55.7	29.8	72	16	0.60	−0.04	3.0
Banff, Alberta	25.36	29.98	+.08	38.4	+3.1	48.9	27.9	65	8	1.90	+0.82	14.0
Edmonton, Alberta	27.70	30.02	+.13	41.8	+1.9	55.2	28.5	72	7	0.38	−0.50	1.0
Prince Albert, Saskatchewan	28.45	30.04	+.06	38.2	+2.1	52.0	24.5	70	4	1.34	+0.51	6.5
Battleford, Saskatchewan	28.26	30.03	+.06	41.9	+4.7	53.7	30.1	75	15	0.54	+0.07	0.2
Kamloops, British Columbia	28.75	30.04	+.11	51.6	+2.7	64.6	38.6	78	26	0.38	−0.01	0.0
Victoria, British Columbia	29.91	30.01	.00	50.5	+3.7	57.8	43.2	64	35	1.04	−1.33	0.0
Barkerville, British Columbia	25.62	29.94	+.08	37.1	+4.0	46.0	28.2	56	16	2.28	+0.46	8.5
Hamilton, Bermuda	29.98	30.15	+.10	64.2	+0.3	69.7	58.8	79	52	3.90	−0.28	0.0

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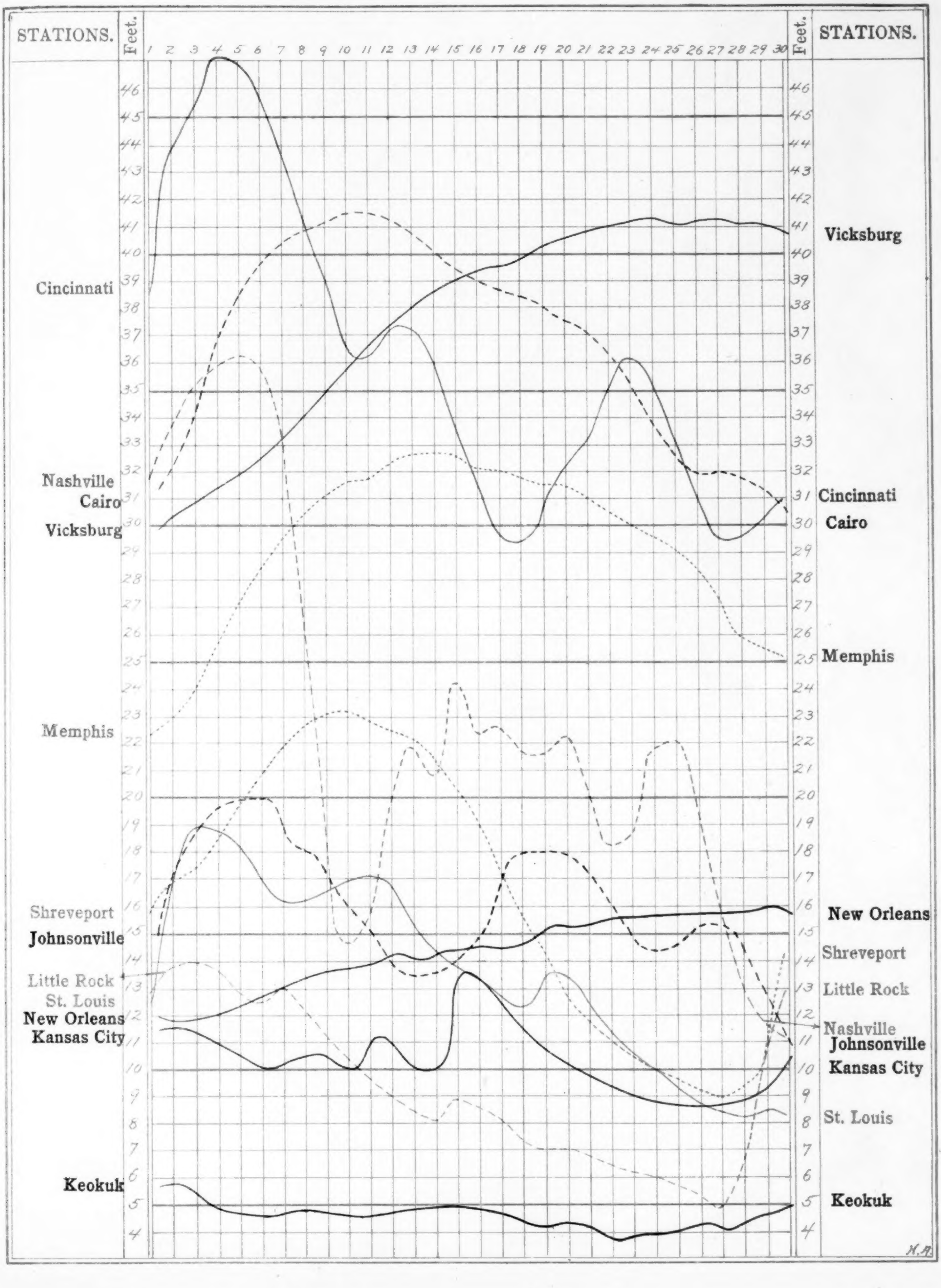
Chart I. Hydrographs of Several Principal Rivers, April, 1914.



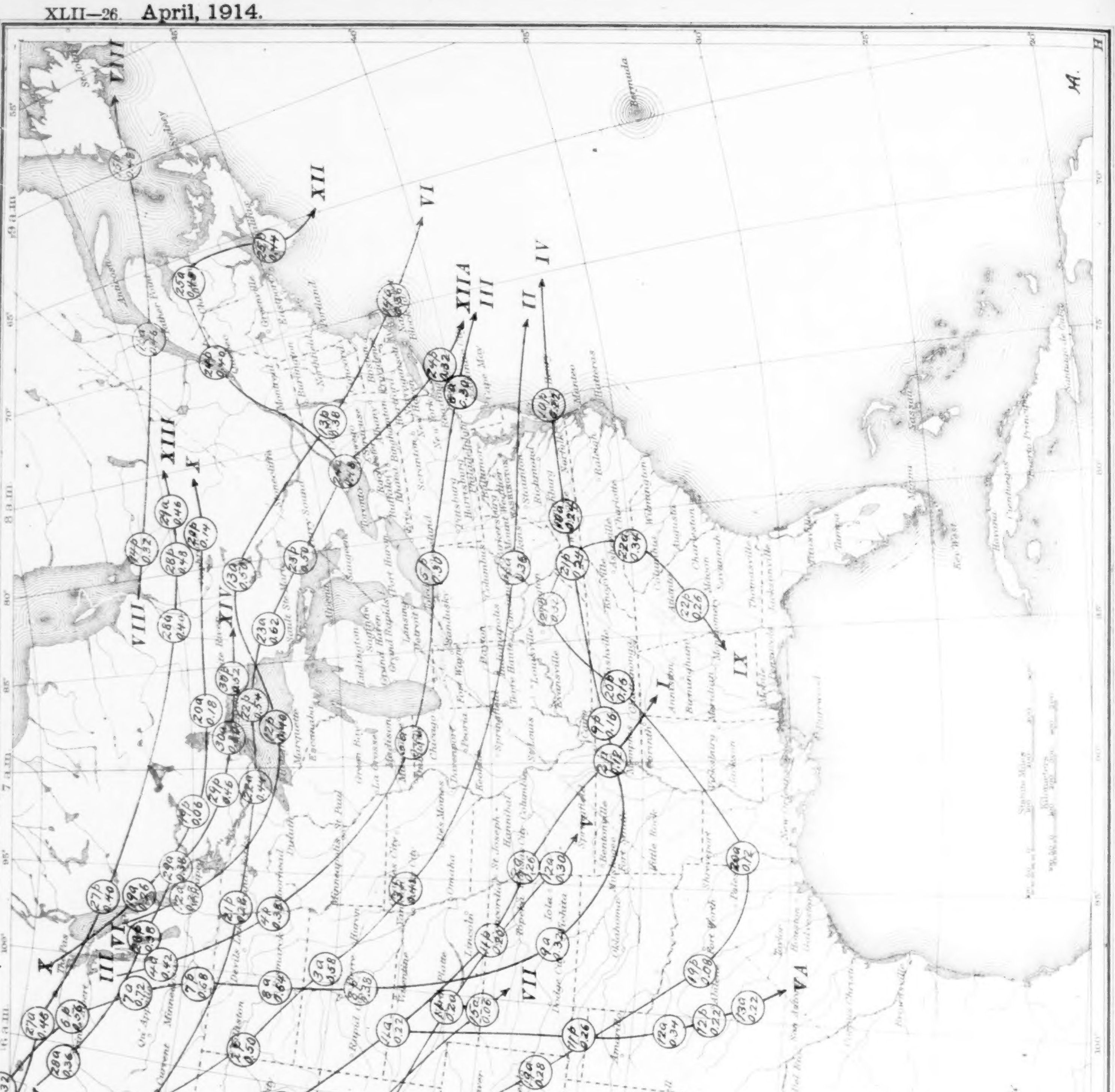


Chart II. Tracks of Centers of High Areas, April, 1914.

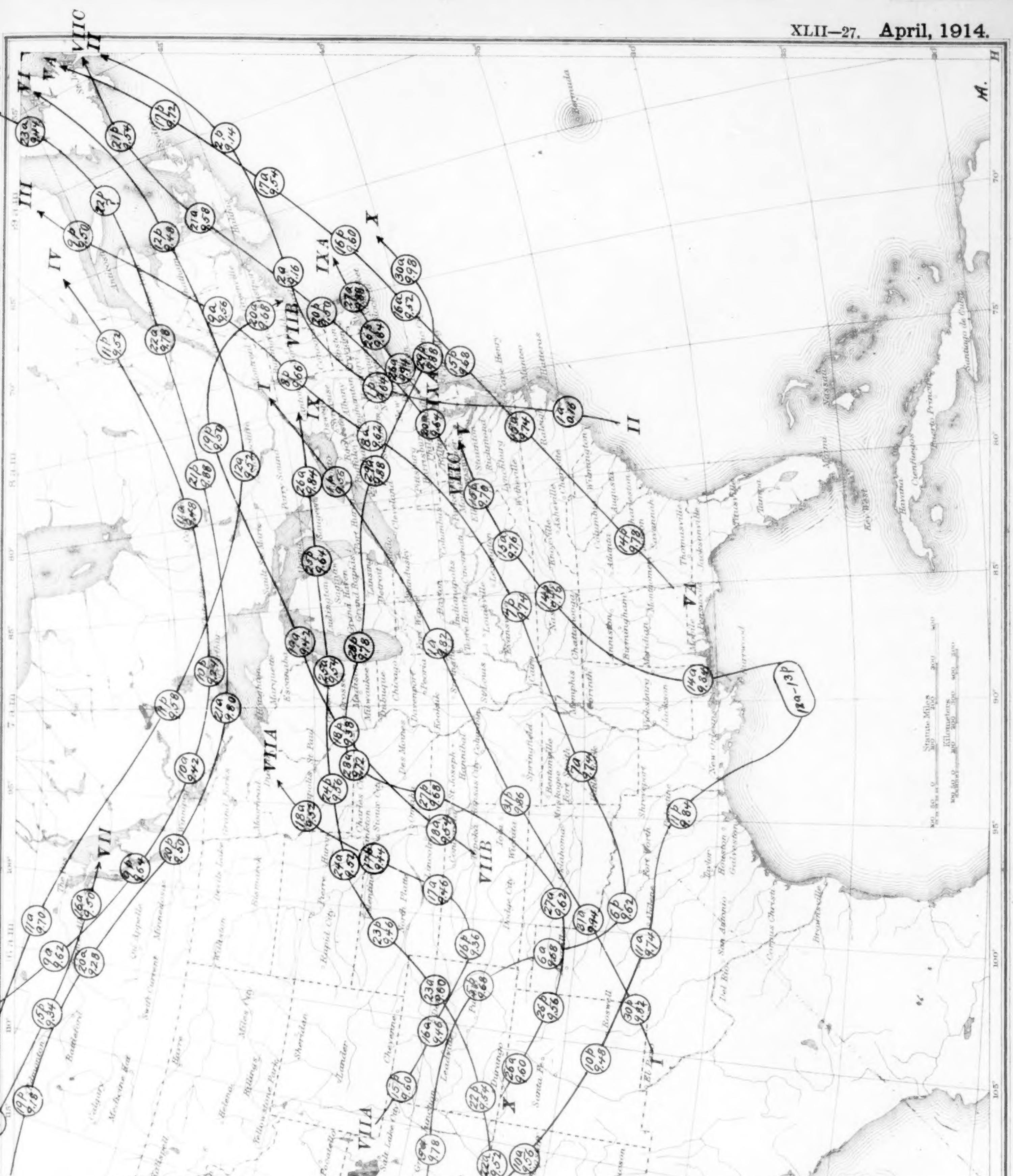


Chart III. Tracks of Centers of Low Areas, April, 1914.

Chart IV. Departure of the Mean Temperature from the Normal, April, 1914.

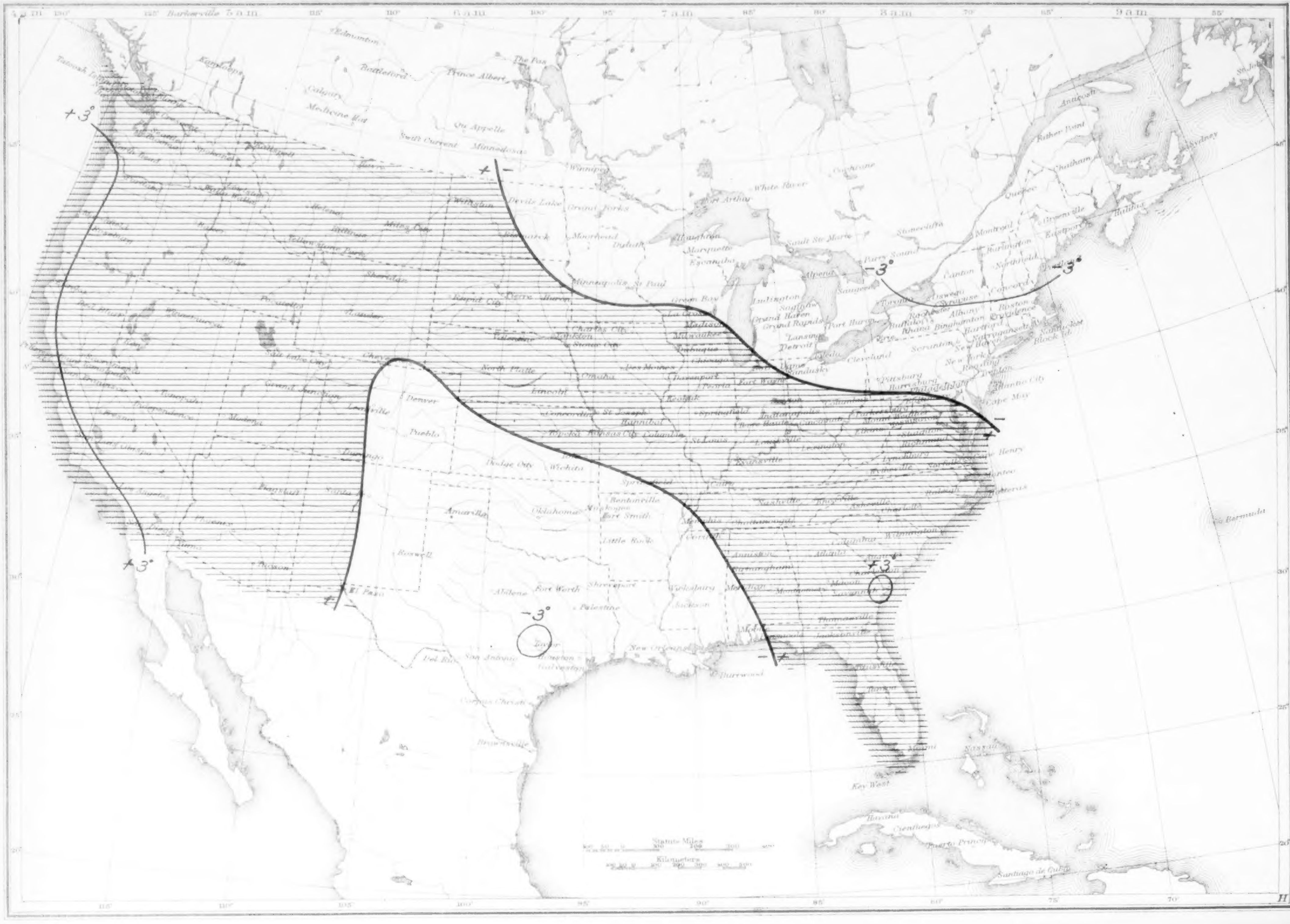


Chart V. Total Precipitation, inches, April, 1914.

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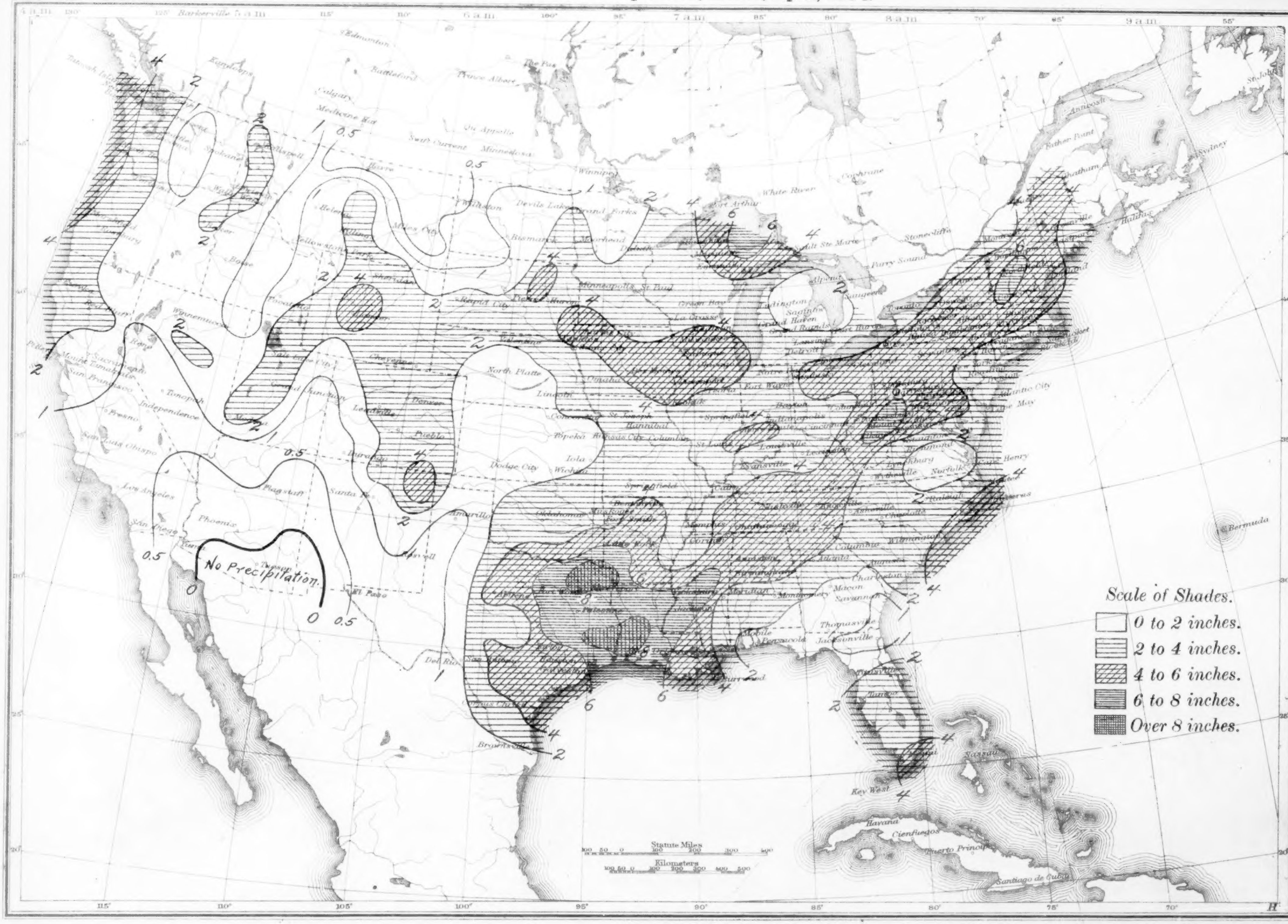
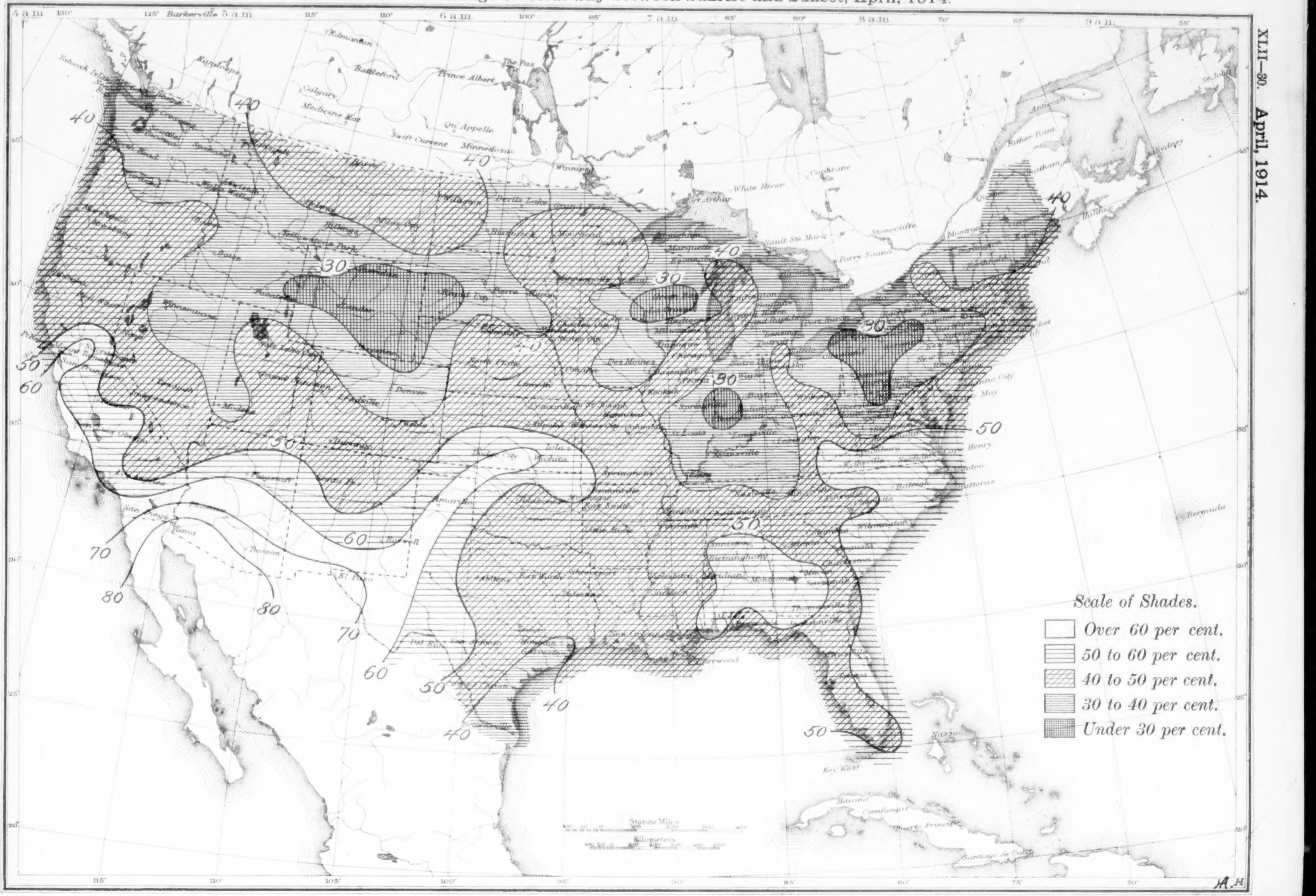


XLII—30.

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, April, 1914.



XLII—31.

Chart VII. Isobars and Isotherms at Sea Level; Prevailing Winds, April, 1914.

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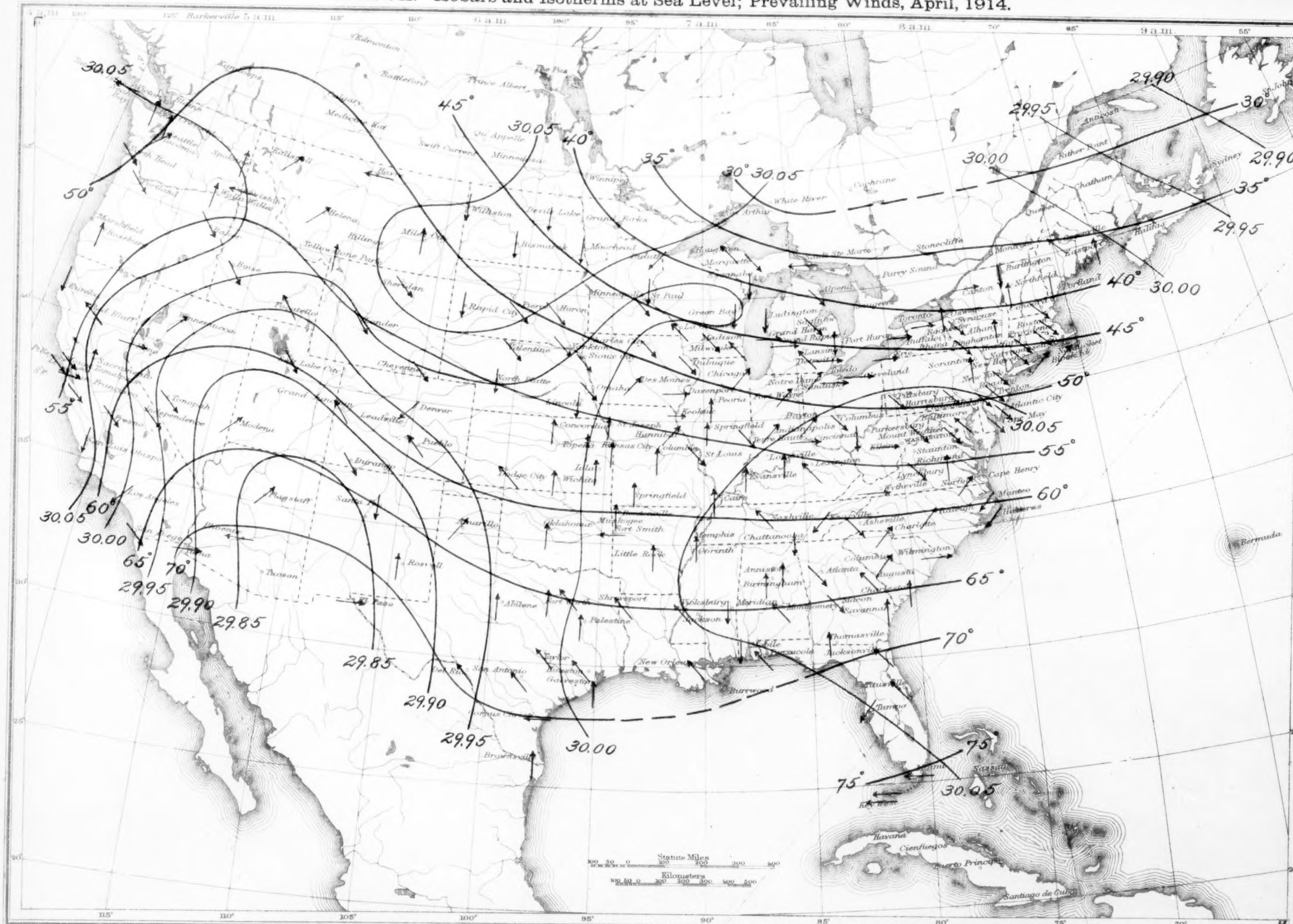

Chart VIII. Total Snowfall, inches, April, 1914.